Investigation of current energy usage on UK farms and of the potential for meeting farm energy needs from renewable resources

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UNRESTRICTED

INVESTIGATION OF CURRENT ENERGY USAGE ON UK FARMS

and of the

POTENTIAL FOR MEETING FARM ENERGY NEEDS FROM RENEWABLE SOURCES

A Research Thesis submitted by

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Abstract

The investigation begins with a brief history of UK agriculture from the start of this century to the present, with particular reference to energy use. This is followed by a study of previously published national aggregated farm energy data broken down by fuel, crop, farm activity and certain energy intensive inputs such as artificial fertiliser. Specific farm energy studies, both actual and hypothetical, are then matched with these national data for the purpose of comparison.

Following an overview of current farm energy conservation techniques, consideration is given to the potential for energy generation on the land using energy crops, farm wastes and solar energy devices. Consideration is then given to the numerous constraints which impede or prevent farm energy generation together with indications of ways in which these may be reduced or overcome.

Following a discussion of how agricultural, economic, and environmental changes are likely to influence farm energy use, the work finishes with a list of conclusions and recommendations. The five main conclusions from the study are that:-

(i) national and specific farm energy data compare well with each other,

(ii) although some of these data are ten or more years old, they fairly represent farm energy use today,

(iii) considerable scope still exists for farm energy conservation, up to 50% saving in some cases,

(iv) fuelwood production, windpower and heat recovery techniques in dairies and animal houses are currently viable on the land and anaerobic digestion of animal wastes can break even where large volumes are available,

(v) in addition to the general constraints impeding conservation and the generation of energy using renewable sources, farmers must accomodate to more specific constraints such as alternative land use and the possibility of global warming.

Six recommendations to assist conservation and the employment of renewable energy techniques on the land are proposed.

Investigation of Current Energy Usage on UK Farms, and of the Potential for Meeting Farm Energy Needs from Renewable Sources.

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Chapter 1. A Brief History of Energy in Agriculture and Introduction to the Main Issues.

1.1 The Period from the Turn of the Century to the Early 1970's.

Although British agriculture is now one of the most industrialised in the world, at the turn of the century it was essentially a labour intensive pre-industrial system. Very little fossil fuel was consumed on the land; the million or so each of farm labourers and horses supplied most of the direct energy which was used to produce food and other crops. Such was the extent of "horse power" use in those days that about one third of lowland arable farmland was set aside for the production of feed for the 1.1 million horses used on-farm as well as the 2.5 million used elsewhere.

By the 1920s British agriculture had reached the stage of semi-industrialisation. There were something like 10,000 tractors in use on the land and most farms had a coal or oil fired engine to drive machines used for processing cereals or animal feed. Electrification of farms was proceeding slowly; by 1935 some 6% of farms had electricity with a combined annual consumption of about 25GWh, or less than 1% of present agricultural electricity consumption (Bayetto 1974). One estimate puts the overall energy input to the land during this period at about 150MJ/ha-yr. (Leach 1976).

After the Second World War the pace of farm industrialisation quickened although in 1950 some two-thirds of farms were still without a mains electricity supply. The period up to the early 1970's was one of great change in British agriculture and energy consumption rose nearly twice as fast as the gross UK fuel consumption. From about 80PJ in 1945, the total of direct and indirect energy input to UK agriculture had risen by 1968 to about 378PJ or 31000MJ/ha-yr of arable and grassland. The labour force declined by some 50% and the energy input per man more than tripled. By 1972 each full and part-time worker was backed by a direct energy input of over 300GJ per year, well above the average of about 150GJ per man-year in a large group of mechanical engineering industries (HMSO 1979).

All this was made possible by the prevailing economic conditions of the time. Whilst rise in energy use and the value of agricultural product remained more or less in step, the cost of fuels and power declined in real terms. Over this period the cost of machinery and the energy to power it remained a steady 17% of all costs for the average UK farmer and fertiliser costs rose only modestly from 7% to 10.5% of all farm costs. By contrast during the same period although farm wage rates were rising, the price of labour declined from 30% to 18.5% of farm costs resulting in an overall decline in labour and energy from 54% to 46% of all costs (Leach 1976).

A declining workforce and trend towards greater energy intensiveness was a significant feature of much of British industry during this time. However, a number of other factors more pertinent to farming have contributed towards this such as the desire to reduce the drudgery of farm labour, improvements in and greater availablility of farm machinery, the development of new farming strategies, the growth in the size of farms (with the opportunity for capital intensive production techniques) and the understandable desire on the part of the farming community, in common with the rest of the British people, to enjoy higher material standards of living.

Unlike the consumer goods industry, a higher farm income cannot be won by the production of novel products or built upon an ever increasing volume of output. The nature of the product and our position in the world market also limits the scope for export. Food demand from British agriculture is thus more or less fixed, and although a slowly rising population, improved diet and trend towards self-sufficiency in food production has led to some increase in demand, farmers can only increase their incomes significantly if there are fewer of them to share the rewards.

Another influence on energy use has been the steady rise in the cost of agricultural land and hence the incentive to produce more food per acre. Thus farmers sought greater yields through artificial fertilisers and other chemicals both to raise the absolute output from the land and tominimise losses due to pests and diseases. Table 1 shows the upward trend in fertiliser and pesticide application over the years. The production of nitrogen fertiliser in particular requires a large input of energy to which must be added the energy to manufacture pesticides, herbicides and other chemicals used on the land. The off-farm manufacture of animal feed is another significant contributor to the demand for energy which is to the ultimate benefit of agriculture (Dept. of Energy 1981).

One way of looking at the extent of fuel energy penetration in agriculture is to compare energy ratios. The energy ratio (Er) is the ratio of the useful food energy output in the edible part of crops to the total support energy given to the crop (excluding the solar and human energy contributions). Thus the energy ratio is a measure of the extent to which energy input into the land up to the farm gate from fossil fuels and electricity results in food energy for human consumption. Support energy is put into the land to produce other food requirements such as proteins and minerals, but the ratio is useful as a means of indicating the "energy efficiency" of the food production process.

The overall Er value for UK agriculture in the 1970s given by Blaxter (1974) and White (1981) is between 0.34 and 0.42, the difference between these figures being due to the assumptions made and data employed in calculating these ratios. The figure of 0.35 given by Leach (1976) for the 1970's suggests quite a large fall from the figure of 0.46 which he calculates for 1952. This indicates that a considerable change in energy use had taken place in the 20-year period between the two figures and that in energy efficiency terms a deterioration has taken place. Much of this is due to the substitution of mechanical for human labour which has already been observed, but it is also due to the change in eating habits and consequent production patterns in UK agriculture over this period.

This can be demonstated by observation of the wide differences in energy ratio values when individual crops are considered. Table 2 gives energy ratios for a range of foods in UK agriculture as suggested by Leach (1976). The table shows that on the whole the production of arable crops is secured with energy ratio values greater than unity whereas the production of meat and similar foods requires energy ratios which are less than unity. Thus sugar beet production has a crop energy ratio of 4.2 whereas for broiler poultry the figure is 0.1. The trend towards lower energy ratio values is due to a combination of greater fossil fuel inputs generally and the change in diet over the years - away from bread, potatoes, sugar and vegetables towards meat, poultry and dairy products (Haines 1982). Indeed much of the current cereal crop which has an energy ratio of about 3.3 is used for animal feed to produce meat with an energy ratio of about 0.37.

The overall farm energy ratio figure, (that is for all farm outputs compared with energy inputs) lies between 0.34 and 0.42 indicating that the production of meat and similar crops dominates the agricultural scene as far as energy use is concerned. The figures for the UK (which may be considered to be typical for industrialised countries as a whole) contrast strongly with the picture in the Third World. For example, Leach's overall energy ratio figure for subsistence agriculture in India - which also includes some estimate for human energy input - is 14.8. For particular arable crops such as millet in Africa, Leach gives a figure of 36.2 - an enormous diffence when compared with Britain and other industrialised countries.

Useful though these figures are as indicators of the input and returns of energy in agriculture, it must be remembered that other factors need to be taken into account when considering their importance. For example, on the input side they make no allowance for the different value placed on particular units of energy; the cost per GJ of electricity to the farmer is more expensive than fuel oil although the former is probably produced from coal which is expected to last much longer at the present rate of useage. On the output side some foods are prefered because of their taste or can be had out of season. An example of this is tomatoes produced under glass which as later work will show are more demanding in energy per unit of crop than almost any other food (Connor 1977).

1.2 From the 1970's "Oil Crisis" to the Present.

The unprecedented rise in the price of crude oil which took place over the period 1973-4 ended the age of "cheap" energy and opened a new era on the history of energy usage. Taking the index of industrial fuel prices in the year 1970 as 100, the oil index in the middle of 1973 stood at about 140. But May 1974 after the OPEC price rise the index had risen to 390 or an increase of some 280% in less than a year (En. Man. 1982). The effect of this was felt in agriculture as everwhere else and it was not long before studies giving attention to the matter began to appear.

An early sign of this rethink was the paper by Pimental (1973) who although writing slightly in advance of the OPEC rise began to pave the way towards a new policy for energy usage on the land. Although writing in the American context and addressing his remarks towards corn production, Pimental makes a number of useful energy saving recommendations as follows:-

(i) manual labour instead of machines for "spot" treatment of corn using herbicides,

(ii) using of tractors and other machines more precisely scaled to the job and run at the most economic speed,

(iii) the substitution of manure for inorganic fertiliser wherever possible,

(iv) the use of nitrogen fixing crops such as legumes in place of nitrogen fertiliser,

(v) alternative weed control measures such as mechanical cultivation and crop rotation,

(vi) using minimum tillage techniques,

(vii) breeding of new strains of corn for insect, disease and bird resistance,

(viii) limiting corn to areas where minimum irrigation is necessary,

(ix) the use of trains rather than road vehicles as much as possible for the movement of agricultural equipment and and supplies.

(x) adoption of a more vegetarian diet and thus away from energy intensive meat production.

Although some of these suggestions may be in conflict with with one other and only applicable when the circumstances are right, they show early thinking towards reducing the energy input to the land from machines and agrochemicals. The suggestions also point towards alternative energy and lifestyle techniques such as the use of more human labour, the application of natural rather than inorganic fertiliser and a change of diet.

Other studies followed in the later 1970's in both Britain and America (such as those by Leach in Britain and Lockeretz in the USA) from which a whole range of strategies for saving and supplementing energy on the land began to emerge. These can be broadly divided into three main areas, namely:

making better use of available energy (conservation);
using solar energy devices (alternatives); and
techniques for the generation of energy from the land through changes in crop and farm management patterns (production).

All these will be considered in detail in later parts of this study.

In common with British industry generally, agriculture was and still remains slow to take up the opportunities to conserve and produce energy on the land. The reasons for this have much in common with the constraints currently preventing action on the energy front in general and these will be considered in some detail in later chapters of this study. As has already been observed, farm energy costs have never been a very significant factor of total farm costs and this coupled with lack of energy expertise and greater preoccupation with crop production has caused farm energy interests to be generally neglected.

There have been some exceptions to this rather gloomy observation. For example, where farmers have been younger, enthusiastic and knowledgeable, experiments have taken place in all areas of opportunity. Many farmers with a straw disposal problem have installed straw burning boilers to heat their houses and farm buildings. There has been some take up of heat recovery techniques employed in dairies. But on the whole farmers have carried on with their normal occupations, perhaps complaining at the size of their energy bills but doing little or nothing to relieve the problem.

The one notable exception to this is the glasshouse sector of horticulture where heating can account for up to 40% of the total cost of the production of protected plants. As a later chapter will show, a variety of techniques have been employed to reduce glasshouse heating costs and with considerable success. Over the ten year period up to 1981 a nearly 50% reduction in heating fuel use was observed (Smith 1982).

It is only in the recent times when farmers have been under pressure to find alternative uses for their land has there been evidence of wider interest in the subject. At the time of writing with energy prices as low in relative terms as they were in the early 1970's there is no financial incentive for farmers to conserve energy so the impetus comes from other sources such as land use, pollution controls and wider environmental concerns such as acid rain and the greenhouse effect, all of which could have considerable influence on the future of farming.

Looking back over the total period of energy use in agriculture which is being considered it this study, Table 3 shows the trends in certain agricultural variables including energy from the turn of the century to the present. This shows that the development towards capital (and hence energy) intensiveness on the land began slowly, accelerated somewhat after the First World War, only beginning to move ahead rapidly after 1945. At about 1950 the number of tractors equalled the number of horses and in the 1960's tractor numbers surpassed the number of full time workers on the land. Today the horse is no longer of any significance in terms of agricultural production and the level of manual labour in proportion to the total workforce in the United Kindom at about 1.5% is probably lower in percentage terms than any developed country in the world.

In 1978 the total annual UK energy take in agriculture up to the farm gate (including energy to produce fertiliser, feed and other agro-chemicals) was about 400PJ or 33000MJ/ha-yr. of arable and grassland, a figure which has probably not changed very much up to the present. Although some of the changes that have taken place since that date will have somewhat altered the pattern of energy use, it is likely that their overall effect will be small for the following reasons. Firstly, absolute energy figures were beginning to level off as farmers became fully mechanised and used fertilisers to the maximum advantage. Secondly, although there was increased use of more specialised machines during the period, these machines tended to be bigger and more efficient thus countering any overall increase in fuel use. Thirdly, although there are examples of farmers using more fertiliser, technical advances in fertiliser manufacture brought about by fuel price increases has enabled some reduction in the energy input to be achieved (Dept. of Energy 1981).

Currently about 1% of total UK energy demand is used directly on British farms. When off-farm indirect energy is taken into account for applications such as fertiliser. feed and transport, the figure rises to between 4% and 5% depending upon which indirect applications are included. Although small compared with the percentage of UK energy used in the domestic and industrial sectors for example, this represents a significant level of energy intensity considering the nature of the industry (White 1981, Lewis and Tatchell 1979).

The Options for Energy Saving and Generation on the Land.

1.3 The Options.

Table 4 lists the range of possible energy saving and generating possibilities under each of the three areas of conservation, alternatives and production. The conservation measures are similar in principle to those which are common in other areas of manufacturing industry. They are based on sound energy management principles aimed at making the most efficient use of all forms of energy. Such measures range from inexpensive "good housekeeping" techniques to those requiring the installation of costly equipment with long payback times.

The solar energy alternatives also have far wider application and in relation to certain technologies such as wind generators and photovoltaic arrays, farming has the advantage of land space over urban applications. A large number of sites and opportunities are likely to exist where solar panels and wind generators will be both socially and economically acceptable. The uncertainty of devices which rely on the sun and the wind for their operation make it unlikely that they can be complete replacements for fossil and other fuel inputs to agriculture, but seems no reason why an integration of solar and fossil fuel sources (taking into account local variables such as farm size, energy requirements and weather conditions) should not be possible and satisfactory.

On the other hand solar and other alternative energy devices may be limited, for a variety of reasons, to specific sites and areas. Geothermal and hydropower energy, although more reliable and consistent in their energy output, also have limited application in farming. Such sources are site specific and although the transport of electricity through the grid system is both practicable and economic the distribution of heat over long distances, unless it its part of a much wider distribution system or there are very special circumstances to be taken into account, is too expensive to be considered.

A study to investigate the possibililty of such integrations was conducted in the United States. Using farm energy data published in the middle and late 1970's and breaking down the data by region, fuel type, farm function and crop, areas were identified where renewables were most likely to be effective. Taking into account their social and economic limitations, it was concluded that up to 25% of on-farm energy could be replaced by solar, wind, hydro, geothermal, biomass and farm residue based renewables (Eakin et. al.1981) .

The third area of energy saving and production on the land is crop related and as such more specific to agriculture than other areas. This area itself can be divided into three parts namely biomass techniques, crop development and the use of organic farming techniques. Biomass techniques use material produced throught the growth, natural or otherwise, of plant and animal matter for the production of energy. This energy can be realised through the direct combustion of the material (such as burning wood) or the conversion of biomass into other solid, liquid or gaseous material which is combustible. The material produced can be sold, used directly on the farm or converted into electricity for local or general use.

Biomass energy is already one of the major sources of energy used by man. It is estimated that in the Third World 43% of energy used is derived from biomass and currently over 2 billion people are almost totally reliant on biomass fuels for their energy needs. By contrast the industrialised nations derive only 1% of their energy needs from biomass. The total of biomass fuels used in 1984 accounted for 13% of the world's annual energy use of 370EJ or the equivalent of some 22M barrels of oil per day (Hall and Overend 1987).

The conversion technologies which can be used to transform biomass into useful energy can take a number of forms. Table 5 lists the main plant and animal inputs to the biomass energy process which are suitable for farm application. Given suitable conditions almost any plant or animal material could be used to produce energy. Over the years numerous research projects have identified the range of materials which are most promising in this respect when all the material, technical, social and economic factors mave been taken into account. The technical aspects of the generation of energy from biomass are a well developed and will be discussed in detail in Chapter 5.

1.4 The Constraints on Energy Saving and Generation on the Land.

The farming industry is aware of the need for greater energy efficiency but is also mindful of the difficulties which stand in the way considering the nature of the industry and its relationship to other activities as far as energy is concerned (ADAS/NFU 1981). A preliminary list of reasons why agriculture has not taken up the cause of efficiency as much as other energy intensive industries could be as follows.

(i) As direct energy costs to the UK arable farmer amount to no more than from 6% to 8% of his total business costs he has been able to absorb or pass on any price increases to the customer. A linear programme computer study in the United States to assess the effect of fuel prices on agricultural income in one American state showed that a 50% price increase in electricity, petrol and gas reduced farming income by less than 3% (Lee 1977). As a simple calculation of the UK scene would produce a similar result to the more sophisticated American study, this indicates that the relatively low level of fuel price sensitivity in UK farming is also true of America.

(ii) Following from the above and on the basis of other U.S. computer studies it has been suggested that the cost of food is less sensitive to fuel price increases than would be the case if there was a shortfall in fuel availability. Dvoskin and Heady (1976) modelled farm energy use and its relationship to food prices observing that if energy costs were doubled a 12% increase in food prices would result, but if energy availability was 10% less than demand this could raise food prices by as much as 60%. Bearing in mind the limitations of this study as far as the UK is concerned in terms of its age and origin, the result is still sufficiently significant to be taken seriously in the UK context. This general conclusion is backed up by later computer studies which suggest that other than in geographically sensitive areas, substantial increases in the production price of farm inputs such as fertiliser and irrigation water are not serious for farm incomes (Forster and Rask 1977, Kizer 1977).

(iii)A third reason is that in the past more profit could be made by producing food rather than energy. The substantial subsidies which are obtainable for crops such as cereals and oil seed rape cause farmers to continue with food production even though this may add to the food mountains of the EEC. There were tax advantages in growing trees in certain parts of Britain (such as the wetlands of Northern Scotland) but the primary objective is wood production for timber and paper making rather than energy. The situation is likely to change as the high cost of producing surplus food in Europe is leading the Common Agricultural Policy into disrepute. Forestry could take over from food production particularly on marginal land and if farm subsidies remain (albeit in a modified form) to include forestry and other energy crops, this reason may cease to be valid.

(iv) The suspicion held by many UK farmers and farming institutions towards relatively unproven technologies such as wind turbines and solar cells. Institutions such as the NFU and ADAS who keep a watch on alternative energy devices for the land remain generally unconvinced of their present value and this attitude will naturally be conveyed to the farmers.

1.5 The Challenge of the Future.

Whatever direct or indirect measures are adopted in the future which have the result of reducing the level of fossil fuel consumption on the land, efforts towards energy saving and production are desirable for the following reasons:-

(i) In order to contribute to the general need to conserve fossil fuel reserves. The case for the conservation of fossil fuel reserves has been well argued and does not need to be repeated here; the contribution which agriculture could make may be small in the context of the energy scene as a whole, but nevertheless large enough to be significant.

(ii) In order to be "ready" for the time when fossil fuel supplies are either in short supply or have become too expensive for the costs to be readily absorbed by the industry or the consumers. It may be argued that the "market" will take care of things but the market is poor at anticipating long term trends and it is wiser to prepare now for the possibility rather than wait for the economy to press against an unwilling and ill prepared farm system.

(iii) To stimulate the research and development which is seen to be necessary in order that products and techniques can be brought to the stage where the market can take over and the farming industry is in the position where it is both willing and able to take advantage of them.

(iv) So that UK agriculture can be used as a "test bed" for energy techniques and devices which can be applied in other countries and noteably in the Third World. This will not only be good for British exporters but also help to reduce the already critical food problems which could result from a world wide energy shortage.

(v) To enable Britain to monitor and if necessary make changes to relevant social and economic factors such as employment, eating habits, health and our place in the Common Agicultural Policy of the EEC. This could be part of a wider strategy involving other areas of the economy such as the much more energy intensive food processing industry.

If on the one hand agriculture has such potential for energy conservation and production and on the other is prevented by economic, social and political constraints from realising these, certain questions can be raised in respect of these constraints with a view to gaining a better understanding of how they operate and seeking for ways by which they may be relieved. Some of these questions are as follows:-

What is the present level of energy usage in UK farming and how does this break down into the various crops and activities on the land?

What is the nature and present level of influence of the technical, economic, social and political constraints?

Given these constraints, what kind of devices and techniques can best be used at present on the land to either conserve or generate energy?

What changes are necessary in the constraints for the penetration of these devices and techniques to be extended?

What other influences and developments both in agriculture and outside are likely to affect the future level of energy use?

It is in order to seek answers to these questions that this research project has been undertaken.

Table 1.

Trends in fertiliser and pesticide application over the years

Years	1940	1950	1960	1970	1980	1985
Fertilisers						
Phosphorus (as P_2O_5)	260	370	450	460	450	450
Nitrogen (as N)	150	210	490	900	1400	1700
Potassium (as K_2O)	100	220	390	420	490	540
Pesticides						
Herbicides			13	56	72	71
Insecticides			19	16	13	14
Fungicides			10	10	24	40
All pesticides	13	43	42	82	109	125

Sources.
HMSO (1979)
Fertiliser Review, (1985 & 1988)
British Agrochemical Assn. Annual Report & Handbook (1982 - 88)

Notes.
1. Figures for fertilisers are for UK applications in 000's tonnes.
2. Figures for pesticides are sales by UK manufacturers for home and abroad in £ millions at 1976 prices.
3. All figures are approximate.

Table 2.

Selected Energy Ratios (Er) for UK Agriculture.

Product.	Ratio.
Grazing grass	5.85
Sugar beet	4.20
Wheat	3.35
Barley	2.40
Silage	2.32
Hay	1.97
Potatoes	1.57
Carrots	1.10
Peas	0.94
Milk	0.37
Beef calves	0.37
Brussel sprouts	0.19
Battery eggs	0.14
Broiler poultry	0.10
Winter lettuce (heated glasshouse)	0.002
Farm Type.	
Cereal	1.90
Cattle and sheep	0.59
Mainly dairy	0.55
Specialist dairy	0.38
All agriculture	0.34
Pig and poultry	0.32
Sheep	0.25

Sources. Adapted from Leach (1976).

Notes. Data can only be taken as average and approximate; figures can vary widely depending upon crop of farm regime. For example grazing grass can vary from 9.1 to 3.7 from a low to high N fertiliser regime respectively.

Table 3.

Trends in certain agricultural variables from 1900 to 1985.

Years	1900	1920	1940	1960	1980	1985
Number of full time employees	1200+	1040	840	510	250	220
Number of horses	1060	960	610	190	neg.	neg.
Number of tractors	neg.	40	100	370	410	420

Sources. Blaxter (1974)
HMSO (1979)
Nix (1984-88)

Notes.

1. All figures are in 000's.
2. Figures are approximate only.
3. Although the figures for employees shows a falling trend it hides the rise to some 900,000 during the later years of the war.
4. neg = negligible.

Table 4.

Energy Conservation and Production Measures on the Land.

(a) Conservation Measures.

Measure.	Energy Form Saved.
Efficient machine use.	Oil, electricity.
Careful use of agrochemicals.	All forms.
Glasshouse conservation	All forms
Plant development.	All forms.
Improved crop drying.	All forms.
Organic farming.	All forms.
Waste heat utilisation	Heat
Reduced transport	Oil

(b) Energy Production - Direct and Indirect Solar Energy Devices.

Devices.	Energy Form.
Windgenerators.	Electricity.
Solar panels.	Hot water or warm air.
Heat pumps.	Hot water or warm air.
Photovoltaic arrays.	Electricity.

(c) Energy Production - Biomass Techniques.

Devices.	Energy Form or Product.
Crop residues.	Heat, solid fuel, biogas.
Animal residues.	Biogas, electricity.
Catch crops.	Biogas, electricity.
Energy crops.	Heat, solid fuel, biogas, oil.

Table 5.

Main Potential Feedstocks for Biomass Energy Production in Agriculture.

Dry Crop Residues.	Wet Crop Residues.
Wheat	Sugar beet
Barley	Potatoes
Oats	Peas for processing
Mixed corn	Beans for stockfeeding
Rye	Brassicas
Field beans	Other legumes
Dried peas	Carrots and parsnips
Oilseed rape	Turnips and swedes
Horticultural Wastes.	**Animal Wastes.**
Orchard grubbings	Dairy cattle
Orchard prunings	Beef cattle
Raspberries	Poultry
Hops	Pigs
Tomatoes (glasshouse)	
Carnations (glasshouse)	
Farmed Forest Residues.	**Rural Natural Vegetation.**
Roots and stumps	Bracken
Tops and branches	Heather
	Rough grass
	Scrub woodland

Source. Adapted from Carruthers and Jones (1983)

Chapter 2. Energy Use in UK Agriculture - 1952 to the Present.

2.1 The Data - its Form and Origins

Any study proposing the replacement of fossil fuel energy with that from renewable resources needs to be based upon an understanding of the present use of energy on the land. This chapter, which has been constructed from published data on agricultural energy use which has appeared since 1952, is designed to show the pattern and change of energy use on the land over the last 30 to 40 years. Not very much was published during the early years of that period; early workers such as Blaxter and Stansfield produced data prior to 1973 but their material was national and global in character lacking the detail of later researchers.

The "energy crises" of 1973 and 1979 inspired much greater activity in this as in other areas of the energy sector. The first works based upon studies from 1973 began to appear in 1975 and continued until the early 1980's. Leach, probably the most significant researcher during this period, published his work in 1976 although much of the material in the study is based on data from the years 1968 to 1972. Others notably works such as those by Spedding and his co-researchers at the University of Reading began to appear from 1975 onwards. Significant workers in the United States during this period include Lockeretz and Pimental, but there seems not to be an American equivalent of the Leach study which took place in Britain.

Little of any significance has been published since 1983 when the last of the studies inspired by the 1979 energy crisis made their appearance. It has been assumed by most workers that the data was "good" for a number of years and could be used as a basis on which to build other studies. This assumption is fair; the rate of change of energy use and division between the various activities in farming is slow and is only likely to show a marked difference from that pattern when there is a major shift in energy prices or farming practice. Agricultural statistics during the 1980's also give support to the view that the earlier figures generally hold good and that no major changes have taken place. Although agrochemical input rose during the period there was a fall in the consumption of fuel which more or less balanced it out and other major variables remained much the same (MAFF 1988).

As far as energy prices are concerned, their current low level relative to that in the early 1980's is likely to encourage more rather than less energy use on the land. However, if the findings of American studies (refered to earlier) are relevant to the UK it would seem that energy usage on the land is more sensitive to fuel shortages and food price variations rather than to changes in the fuel price itself (Dvoskin and Heady 1976). Shifts in energy usage are thus more likely to come about through alterations in farming practice; for example the present uncertainty in the future of British farming due to overproduction and the Single Market policy of the EEC which will come into effect in 1992 could have a greater influence than changes in the fuel price.

All the data presented in the tables which follow are aggregated and take almost no account of variations such as farm size and location. However, it is possible that some data, such as the energy accredited to machines of different capacity, reflects farm size. Location is represented by the difference in greenhouse energy requirements between North and South of the UK. On the whole, the relatively small size of the UK makes it unlikely that significant energy use variations exist between between the various regions due to weather pattern differences.

Moreover any attempt to identify regional differences would probably be undermined by variations at farm level such a farm practice, the age and condition of equipment, the quality of the land, farm elevation, the skill of the farmer and changes in weather conditions from one year to another. The one exception to this could be farms size; larger farms are probably more efficient in energy use and may have newer, bigger and a larger variety of equipment. Even this may be minimised by greater energy intensiveness in large farms, and as such farms tend to be richer they may be less concerned to keep energy cost under close control.

The two largest energy requirements, namely fertilisers and fuel for machines, are likely to be much the same all over the country in any case. This is could also be true for specific activities such as crop drying and feed processing although the former may be somewhat greater in the wetter parts of the country. Other regional factors may tend to make the overall balance of energy use on farms even out; for example greater tractor fuel may be necessary in the hillier farms of the north but this could be balanced in the South East due to heavier irrigation requirements.

Most of the data in the tables have been obtained using a macro-approach with the help of various assumptions and estimates based on general observations. One part of this approach is the process analysis method. This involves tracing back individually all outputs and inputs from the finished product (ie food at the farm gate) to the fossil fuel energy sources. The method is laborious and subject to error as in some cases quantities are difficult to measure or are simply unknown.

Another method is based on the use of input-output tables which record monetary transactions between all those involved in the sale of energy which ultimately finds its way onto the farm. The weakness here is the high level of aggregation in the data and the exclusion of many items of goods and services which involve energy but fail to be counted.

Much of the data using the macro-approach is likely to be out of date when it gets to the researcher or seriously undermined by inflation or changes in economic factors such as the exchange rate. Some adjustment can be made for this but only at the cost of making assumptions which may be at variance with reality.

The micro-approach to data analysis involves the study of energy use on individual farms. This has the advantage that the final figure for energy use on a particular farm will be more accurate than any aggregated analysis and therefore more useful to that farm. The weakness of this approach is that data are unlikely to be representative and much of it, relating to things like fertilisers and machines, must still be obtained from aggregated sources.

An example of the use of estimates in farm energy is in the division of electricity. Firstly there is the division between the electricity used for agriculture and that for domestic and other purposes. In his study of farm energy Leach chose to divide electricity between these two in the ratio 60%:40% respectively. Other studies have favoured a 70%:30% split but whatever the case it is generally agreed that the ratio is of this order. Within the agricultural sector some estimate need to be made of that which is used for ancilliary purposes such as equipment maintenance and repair. Leach uses a ratio of 0.4:1 for 'depreciation energy' to work energy for tractors within the power range 37 to 67kW and later reseachers appear to have accepted this figure as valid.

Looking at the data as a whole and recognising that considerable differences will exist at the level of individual farms, the data should be viewed as a guide only. Leach claims that an accuracy of 10% or better can be assumed for the absolute farm energy inputs (tables 1 and 2 in this work). All that can be said with reasonable certainty is that these data are of the right order of magnitude and no reliance should be placed on the third figure and little of the second in each case.

As far as the presentation of the data from various sources is concerned, some rounding off has been done but in general figures have been left as given in the original work. Where calculations for this study have been made these data has been worked to three significant figures.

2.2 Discussion of Particular Tables

Table 1 shows four attempts at an overall farm energy balance sheet. The columns have been placed in date order and even though a ten year interval exists between the first and last column they suggest that the overall farm energy demand during that period was more or less of the same order. This contrasts strongly with the mix shown in Leach's data in table 2 but this covers a twenty year period compared with the ten of table 1 and is all pre-1973 when energy demand was growing generally.

Changes in fuel type can be seen over this period, with the decline in the use of coal and coke and the rise in the use of oil and electricity. These data also indicate an increase in the use of fertiliser and machinery during the period but as discussed in Chapter 1, other factors such as the improved machine efficiency and energy savings in fertiliser manufacture have most likely countered any increase due to these and other causes.

The apparently heavy use of energy on dairy farms demonstrated by Lewis and Tatchell (table 3) can be largely accounted for by the energy content of concentrated feed and this is supported by the Leach figures in table 4. Table 3 shows that the operation of milking equipment accounts for the heavy use of electricity in comparison with other types of farm. Intensive pig and poultry production is also heavy in energy use due to feed requirements and the high electricity figure is probably accounted for in space heating (table 4).

Table 3 shows the enormous use of energy in the glasshouses sector. This is very much an average figure, for the winter lettuce and tomato figures given by Leach (table 6) suggest that wide differences exist depending upon the crop. Glasshouse owners have been particularly successful in reducing energy usage (mainly oil) since 1973. In the ten year period 1971-81 glasshouse energy requirements fell by nearly 50% (Smith 1982).

The figures for cereal production from a variety of sources (tables 6 and 7) generally agree with one other. The difference in the two fodder crops, lucerne and ryegrass, is essentially accounted for by the absence of N fertiliser on the one and its heavy use in the other. General agreement is apparent between the vegetable crop data from non-Leach sources and the Leach breakdowns in table 8. The tables also show the extent to which N fertiliser can influence the overall energy take on arable crops.

Stansfield and Leach give similar data for fieldwork energy (table 9). These are likely to have been obtained from field trials so can be assumed to be more reliable that some other data. However, there is considerable scope for variation depending upon the soil type and condition, tractor efficiency and ploughing methods to account for any differences.

The data for livestock production (table 10) illustrates the scope for considerable differences which can appear in this field of research. Apart from those due to accounting these differences can largely be attributed to feed, fertiliser and heating choices in the different regimes. As the breakdown figures in tables 12 and 13 indicate, farming differences are bound to play a significant part in energy use, but the data still shows totals which are of the same order of magnitude taking into account the final product in each case.

Tables 14, 15 and 16 on feed inputs are likely also to be based on field trials and therefore fairly reliable. Further data on feed and silage production (tables 17 and 18) once more demonstates the influence of the level of N fertiliser use on total energy input. Table 18 show that the yield, although increasing under high fertiliser input regimes, falls far short of the proportionate increase in energy used.

As would be expected, table 19 shows grain drying is much less energy demanding per tonne of product than drying grass or hay. The table suggest that the size and type of dryer has considerable influence on the amount of energy used and as one would also expect, grass drying is considerably more energy demanding than hay drying.

Little data seems to be available for the energy used in horticulture. Morris's data for various horticultural activities (table 20) is the total for the UK and in view of the aggregated nature of the data is of limited use. There is scope here for further research particularly to break down the data by type of crop and with reference to the glasshouse figures, by location and construction of building.

2.3 Conclusions on the Tables.

The tables indicate the areas of high energy consumption and in a number of instances, the fuels which are involved. Certain materials and activities stand out as candidates for attention and the mode, form and size of equipment which could be used to reduce or provide the energy currently served by fossil fuels are suggested.

The tables also show that the principal areas of energy usage are N fertiliser production, feed processing, machine usage and the drying of crops. The intensive production of vegetable and animal products also require a heavy energy input, as do attempts to produce large yields of cereal crops with the heavy application of agrochemicals. Milk production is seen to be heavy in energy demand with milk cooling and dairy plant cleaning and the running of auxiliaries taking most.

Oil (and its derivatives) is the major fuel employed on farms and electricity, although seen to be growing faster than oil over the years, is still some way behind in second place. As in other areas of industry, the employment of solid fuels like coal and coke is in decline but the use of wood (not listed in the tables) is becoming more popular.

The heaviest energy users, namely fertilisers and feed processing, which account for nearly half of all energy employed on the land, are outside of the control of farmers other than in the amount they employ. Successful efforts to reduce these inputs would make a far larger contribution to the take of energy on the land than any other measure.

With no immediate prospect in the UK of using alternatives to oil for the powering of agricultural vehicles, conservation is the only way forward here also. Attempts are being made to power agricultural vehicles with biogas or vegetable oils but so far trials have proved to be unsatisfactory or require new engine designs (Far. Wk. 1986a & Hall and de Groot 1987).

Although electricity is not the major energy resource on the land it is probably the one which can most easily be produced. Gas can also be produced on the farm but apart from the exceptions of glasshouse and livestock heating, it is little used and thus is best employed on farm as a feedstock for the generation of electricity.

There is scope for matching of the energy which has to be extracted from milk to the need for energy in the dairy for cleaning. Here is an ideal application for an energy transforming device using the refrigeration cycle - the heat pump. The heat pump may also be used in other areas of farming such as drying and glasshouse heating, but if the electricity required for the pump is taken from conventional generation sources the overall efficiency may be no greater than using an efficient gas boiler.

At the wider level it is evident from the tables that certain foods such as winter lettuce and intensive poultry which are expensive in energy are able to be produced because the general public are prepared to pay the price. Normal pressure of market forces on the farmer and grower will cause them to keep their energy take to a minimum, but otherwise such energy intensive enterprises will continue to exist even though they could be regarded as inessential for the satisfactory feeding of the nation.

Table 1 National Farm Energy Inputs

Source	Leach (1976)	Wilson (1980)	Blaxter (1975)	White (1981)
Fuels				
Coal and Coke	8.9	4.1	4.3	1.2
Petrol products	69.7	85.0	82.8	70.0
Electricity	29.8	33.0	57.4[2]	37.2
Fertilisers				
N	62.6	)	94.6	)
P	6.7	)83.0	8.4	)93.3
K	4.1	)	3.9	)
Lime	8.4	-.-	21.2	-.-
Agrochemicals	8.5	8.5	1.2[3]	8.5
Machinery	31.8	52.0	48.8	40.0
Processed feed	51.3	51.3	2.1[4]	52.5
Transport				
To farm	)16.3	)16.3	3.5	16.3
From farm	)	)	12.2	
Buildings (materials and construction)	22.8	22.8	-.-	22.9
Imported feed	53.2	53.2	-.-	53.2
Miscellaneous	4.3	4.3	-.-	4.3
Totals	378.4	413.5	340.4	399.4
Year of origin of data	1968	1973	1973-5	1978

Notes

1 All data in PJ, ie 10^{15} J.
2 Including farm energy used domestically.
3 Probably does not include all chemicals.
4 Probably farm produced feed only.

Most of the data is produced from national energy and material statistics brought to the same base by making various assumptions on energy content or estimates from other sources. Some of the data from later work seems to have been 'borrowed' from Leach, eg transport, buildings, feed and miscellaneous energies.

Table 2. National Farm Energy Inputs, 1952 - 1972.

Year	1952	1960	1965	1968	1970	1972
Fuels						
Coal & coke	16.5	13.6	10.2	8.9	7.3	4.7
Petrol						
(power)	59.5	51.4	43.7[5]	45.6	49.0	56.9
(dryers)	5.7	5.2	20.4[5]	24.2	24.8	30.5
Electricity	6.1	19.1	28.2	29.8	32.7	34.7
Total Fuels	87.8	89.3	102.5	108.4	113.8	126.8
Fertilisers						
N	14.7	32.8	45.9	62.6	67.4	73.8
P+K	5.3	10.5	10.8	10.9	10.9	10.8
Lime	8.0	8.0	8.0	8.4	8.8	8.9
Total Ferts.	28.0	51.3	64.7	81.9	87.1	93.5
Machinery				31.8		
Buildings				51.8		
Total others	(50.0)	(60.0)	(72.1)	83.6	(88.3)	(95.9)
Feedstuffs	(75.5)	(86.5)	(85.7)	104.5	(106.3)	(94.0)
Overall total (rounded)	241	287	325	378	395	410

Notes

1. All data in PJ.
2. Data assumes 1968 technologies and practices throughout, probably accurate to 10% or better.
3. Figures in brackets are probably estimates worked forward and backward from the 1968 data and modified in the light of observed trends as seen for example in the Annual Farm Price Reviews.
4. All data from Leach (1976).
5. The sharp change in the division between petrol use in 1965 compared with earlier years is probably due to a change in the method of accounting.

Table 3 <u>Energy Use by Farm Type in the UK</u>

Farm Type	Dairy farms	General crops	Upland meat	Glasshouses	
Fuels					
Coal				20,500	(4.4)
Oil	4.7	6.9	2.1	to	(82.0)
Gas				26,000	(5.8)
Paraffin					(9.8)
Electricity	4.9	2.3	0.6		
Machinery					
(moving)	5.0	6.7	2.0		
(fixed)	3.9	1.3	2.1	See notes 5,6 & 7	
Variables[4]	37.6	9.3	8.6	for glasshouses.	
Misc.	0.5	0.6	1.0		
Totals	56.6	27.1	16.4		

<u>Notes</u>

1. All data in GJ/ha-yr.
2. The first three columns from Lewis and Tatchell (1979).
3. Data in the first three columns relate to the year 1974-5
4. Variables include fertilisers feed, chemicals, etc.
5. Calculated from data given in Sheard (1975) and Bailey (1982). Range of heating energy usage depends upon locality and crop. Figures given represent energy required to maintain a temperature of 15.6°C.
6. Figures in brackets are percentages heated by each fuel given by Bailey.
7. Energy used for purposes other than heating is too small to be significant in glasshouses.

Table 4. Energy Use by Farm Type - England and Wales

Farm Type	Dairy Special	Dairy Mainly	Cattle & sheep	Sheep only	Pigs & poultry	Cereals
Fuels	13.2	9.7	6.4	2.2	18.8	9.0
Electricity	4.9	3.3	1.2	0.4	14.4	1.9
Machinery	2.7	2.3	1.2	0.3	5.1	2.4
Bought feed	14.1	9.8	2.7	1.0	69.4	2.1
Fertilisers	6.4	5.1	2.6	0.5	5.5	5.4
Misc.	3.9	4.4	1.8	0.3	10.5	4.5
Totals	45.1	34.6	15.8	4.6	123.6	25.3

Notes.

1. All data in GJ/ha.
2. All data adapted from Leach (1976).
3. Totals slightly different from calculated values due to rounding off.
4. Data based on year 1971-72 and adjusted using MAFF farm income statistics.

Table 5. Energy Use on Farms by Fuel, UK and England and Wales

Petroleum Fuel UK	PJ	Elect[y] England & Wales	PJ
Tractors and land machines	42.1	Livestock production	5.0[1]
Vehicles, lorries and cars	13.7	Arable production	1.2[2]
Glasshouse heating	21.8	Horticulture	0.6
Other heating plus drying	9.1	Domestic and misc.	4.7
Total	86.7[3]	Total	11.5[4]

Notes.

1. Made up of milk production, 3.34; feed preparation and delivery, 0.56; environmental control, 1.08; effluent disposal, 0.018.
2. Made up of grass drying, 0.068; hay drying, 0.21; grain drying, 0.86; potatoe storage, 0.036; vegetable storage, 0.032.
3. Data from Wilson and Brigstocke (1980) for years 1972-3.
4. Data from Bayetto (1974) also for year 1972-3 with forcast of a rise to 17.34 PJ by 1980.

Table 6. Energy Use by Arable Crops

Source	1	2	3	4	5	6
Cereals						
Conv. drill				14.72		19.3
Dir. drill				13.22		
Winter wheat	18.89	10.52	18.9		10.9	21.22
Barley						
Grain only		8.8			17.6	17.6
Grain + straw					18.4	
Oats + barley	15.66					
Maize	26.37				18.8*	
Lucerne		2.815			8.8*	
Ryegrass		31.00				
Grass						
170 kg of N					27.8*	
270 kg of N					35.6*	
Potatoes	28.31		34.0		19.9	52.0
Sugar beet	22.59				22.6	25.2
Swedes (carted)					9.8	
Kale (grazed)					10.0	
Beans	11.69					
Peas	10.93				4.1	
Brussels	47.94					32.4
Carrots	27.59					25.1
Onions						93.4
Lettuce (winter)	4550 to 6060					
Tomatoes			40050			1300[7]

Notes

Sources
1 Leach (1976)
2 Spedding and Walsingham (1975)
3 Spedding and walsingham (1978)
4 Wilson and Brigstoke (1980)
5 ADAS/NFU (1981)
6 White (1981)

7. This figure is probably out by a factor of 10. Can vary by a factor of 3 depending upon the planting date.
8. Source 2 data is given as energy input up to harvesting.
9. For swedes and kale, machinery energy not included.
10. Data with * was crops grown for silage only.
11. All data in GJ/ha-yr.

Table 7 Cereal Crops Breakdown

Source	1	2	3	4	5
Fertiliser					
N	10.5	7.99	10.95	12.77	7.76
P	0.7	0.75	0.7	0.7	0.67
K	0.45	0.4	0.4	0.4	0.43
Fieldwork	4.53	1.24	2.47	0.84	3.2
Equipment			2.78	1.78	1.29
Sprays	0.4	0.16	0.14	0.28	0.4
Seed			0.72	0.72	
Drying	2.29		2.99	2.99	1.87
Totals	18.87	10.52	21.21	21.15	15.66

Source	6	7	8	9	10	11
Fertiliser						
N			6.44		28.86	4.48
P	6.63	6.63	0.62	0.7	0.9	0.63
K			0.37	1.09	0.43	0.4
Ploughing	0.74					
Sec^{y} cult^{n}	0.24					
Prep. seed bed	0.15					3.82
Drill & harrow	0.15	0.18	1.24	0.83	0.84	(fuel)
Rolling	0.15					+
Combining	0.55	0.55				2.84
Baling	0.06					(equip^{t})
Bale Handling	0.15					
Stubble cult^{n}	0.2					
Spraying	0.05	0.09	0.14	0.19		0.4
Drying	5.76	5.76				13.8
Totals	14.72	13.22	8.8	2.82	31.00	26.37

Notes

Sources

1 Leach (1976) - for winter wheat.
2 Spedding and Walsingham (1975) - for winter wheat.
3 White (1981) - for conventional winter wheat.
4 White (1981) - for direct drilled winter wheat.
5 Leach (1976) - for oats and barley.
6 Wilson and Brigstocke (1980) - for unnamed conventional cereals.
7 Wilson and Brigstocke (1980) - for unnamed direct drilled cereals.
8 As for 2. - for spring barley.
9 As for 2. - for lucerne.
10 As for 2. - perennial ryegrass.
11 Leach (1976) - for maize.

All data in GJ/ha-yr.

Table 8 Vegetable Crops Breakdown

Crop	Potatoes	S.Beet	Peas	Beans	Brussels	Carrots
Fertiliser						
N	14.0	12.80		1.34	25.12	6.56
P	2.45	0.70	0.7	1.93	1.40	1.47
K	2.25	1.35	0.45	1.24	0.9	0.94
Fieldwork	6.23	5.04	5.29	2.38	6.99	8.5
Equipment	7.84	4.8	4.02	1.31	4.8	2.4
Sprays	1.24	1.09	0.14	0.28	0.67	0.56
Seeds		1.08		1.56	2.22	1.34
Drying				1.43		
Storage	2.14				0.98	2.11
Extras		0.53	0.33	0.22	4.86	3.71
Totals	36.15	27.39	10.93	11.69	47.94	27.59

Notes

1. For winter lettuce the data are:- Heating, 4010 - 5360; CO_2 enrichment, 308; electricity, 56-205; fungicides, 10; fertiliser, 0-12; sprays, 1; boxes, 107; seeds plus compost, 45; sundries, 11, making a rounded total of 4550-6060. The lower heating figure will be for the south of England and higher figure for the north. Heating figure also depends upon whether the seeds are naked or pelleted.
2. All data from Leach (1976).
3. All data in GJ/ha-yr.

Table 9 Fieldwork Energy Breakdown

Stansfield (1975)	MJ/ha	Leach (1976)	MJ/ha
Ploughing	653.6	Plough (0.2m deep)	840
Rotary cultivating	516.8	Rotary cultivating (deep)	1020
Sub soiling	364.8	Rotary cultivating (shallow)	560
Chisel ploughing	319.2	Secondary cultivation	280
Disc harrowing	235.6	Combined drill/harrow	170
Spring time harrowing	197.6	Direct drill/harrow	210
Drilling, mowing, tedding, baling, fertiliser spreading.	121.6	Light cultivation	170
		Fertilising (inorganic)	86
		Rolling	56
Rolling	83.6	Spraying	52
Spraying	45.6	Transport (seed & fertiliser)	20

Notes

For Leach a 55kW tractor was used in average conditions.

Table 10 — Energy Use for Livestock

Source	1	2	3	4	5	6
Units	GJ	GJ/ha-yr		MJ/kg		
Milk	31.05[7]	32.5	26.3	9.12	13.64	6.0
Eggs	0.597[8]	22.5		49.5	40.22	0.602[8]
Broilers	0.066[9]	29.4		31.59		0.053[9]
Lamb		10.1				
Beef		10.5	33.0	43.1	47.72	
Turkeys		23.6				
Pork		18.0		32.42		6.736[10]
Breeding sows				51.2	40.11	
Heifers (2 yr. old)	14.63 to 21.03[11]					

Notes

Sources

1. Leach (1976).
2. White (1981).
3. Spedding and Walsingham (1978).
4. Spedding et.al. (1983) for intensive systems.
5. Spedding et.al. (1983) for extensive systems.
6. Morris et.al. (1983)
7. Data is per cow-year.
8. Data is per hen-year.
9. Data is per bird.
10. Data is per pig.
11. Level depends upon energy content of food.

Table 11 — Dairy Activities Breakdown

	MJ/cow-year
Milk plant cleaning	576
Milk cooling	396
Vacuum pump	198
Lighting	126
Udder washing	90
Space heating	25.2
Miscellaneous	28.8
Total	1440.0

Source

ADAS/NFU (1981)

Table 12 Livestock Energy Breakdown

Source	Leach	(1)Spedding	(2)	Morris	(3)Spedding	(4)
Type	<-------------------	Dairy	--------------	------------------>	<-----Beef	----->
Raised heifer	3660					
Concentrates	10620	14921	8921	17100	12855	7109
Grazing	9480	14361	8917	7100		9752
Silage				4800		
Vet & medicine	470	585	585			
Bedding	350	341	341		985	1140
Water	450					
Buildings	900	2919	3307		829	1950
Fuel		11292	14952		973	
Machines		4419	5852		339	2224
Electricity	4580	5971	10589	4400		1917
Misc.	540	1121	1121	4000	630	630
Totals	31050	55960[2]	54585[3]	37400[4]	17111[2]	24722[3]

Notes
1. Leach (1976). Figures for friesians averaged over two years.
2. Spedding et. al. (1983). Columns (1) and (3) for intensive stock.
3. Spedding et. al. (1983). Columns (2) and (4) for extensive stock.
4. Morris (1983). Data given as a "basic system" with variations ranging over feed and fuel changes.
5. All data in MJ/animal-year.

Table 13

Source	1	2	3	4	5	6
Animal	Poultry	Rabbit	Sows	Weaners	Eggs	Broilers
Concentrates	112.73	79.54	11038	1759.0	371.0	43.0
Vet & medicine	1.83	0.71	369	5.0		0.15
Bedding	0.27		202	12.0		0.26
Water	0.13	0.12				
Buildings	16.95	10.76	1456	75.0	21.0	0.27
Heating	3.71	10.45	760	931.0	138.0	4.2
Tractor fuel	1.47	1.54	283	25.0		
Machines	0.91	0.70	192	16.0	(negligible)	
Electricity	13.91	5.59	2549	9.0	58.0	12.0
Miscellaneous			248	34.0	1.9	1.4
Totals	151.91	109.41	17597	2866	589	61.3

Notes

Sources 1&2, Spedding (1981); 3 to 6, Spedding et. al. (1983).

Units Poultry and rabbit data in MJ/progeny-yr. for 100 progeny/hen and 80 progeny/doe respectively all reared to slaughter.
Sow data in MJ/yr., weaner data in MJ/baconer, battery eggs in MJ/hen-yr. and broiler data in MJ/broiler.

Table 14 Feed Energy Inputs (Processing)

Feed type	Straights	Compounds
Feed growing	5190	6580
Feed processing	1190	4740

Table 15 Feed Energy Inputs (Conserving)

Hay, field cured	5198
Hay, barn dried	37191
Silage with additive	16515
Silage without additive	7875
Dried grass	207953

Table 16 Feed Energy for on Farm Mixing

Mixer type	Without Cuber	With Cuber
Support energy in plant	69	106
Milling and mixing	240	240
Feed movement	12	12
Cubing	---	240
Total	321	598

Notes for tables 14, 15 and 16

1. Tables 14 and 15 from Spedding (1981).
2. Table 16 from ADAS/NFU (1981)
3. Tables 14 and 16 data in MJ/t.
4 Table 15 data in MJ/ha-yr.

Table 17 Feed Production Energy Breakdown

Crop	Grass	Lucerne	Hay(1)	Hay(2)	Hay(3
Fertilisers	3100	300	7480	21620	30340
Fuel	600	600	---	2570	2570
Machinery	600	600	2000	3530	3530
Drying	12000	12000	---	---	27800
Fans and auxiliaries	1900	1900			
Totals	18200	15400	9480	27720	64240

Notes

1. Grass and lucerne data from ADAS/NFU (1981) in MJ/t.
2. Hay data from Leach (1976) in MJ/ha-yr.
3. Hay(1) is for one cut and graze.
4. Hay(2) is for three cuts and low N fertiliser.
5. Hay(3) is for three cuts, high N fertiliser and drying.

Table 18 Silage Production

System	1	2	3	4
Fertiliser	14400	23310	21620	30340
Fuel	6180	6180	5640	5640
Machinery (field)			4980	4980
Machinery (silage)			7730	8850
Equipment	7076	7076		
Energy totals	27746	35566	39970	49810
Yields (kgDM/ha)	7299	9440	10300	11800

Notes

1. System 1, lower NPK fertiliser inputs.) ADAS/NFU (1981)
2. System 2, higher NPK fertiliser inputs.)
3. System 3, low N fertiliser input) Leach (1976)
4. System 4, high N fertiliser input)

Table 19 Grain and Fodder Crop Drying

Grain[1]	Direct Energy	Total Energy
Direct fuel burner[3]	41.0	46.5
Maize dryer[3]	82.4	105.8
Platform dryer[3]	85.3	112.5
Continuous dryer[3]	82.5	134.2
All electric radial flow	43 - 54	173 - 216
All electric floor type	43 - 58	173 - 230
All electric vertical flow	54 - 65	216 - 259
Hay[2]		
Direct fuel burner[3]	1630	1850
All electric Dutch Barn	324 - 468	1296 - 1872
All electric walled barn	540 - 864	2160 - 3456
All electric mesh floor	648 - 1296	2592 - 5184
Dried grass		
Large unit (10t/hr.)[3]	9870	12930
Small unit (4t/hr.)[3]	14070	16510

Notes

1. For each percentage moisture content removed.
2. For each tonne of finished product.
3. All these methods use some electricity, mainly for fans.
4. The total energy data includes losses due to energy conversion processes and efficiency constraints.
5. Large variations can occur in these data (up to 50% of the energy required) due to weather conditions and dryer differences.
6. To these data must be added transport and depreciation energy needs but these tend to be small compared with drying requirements.
7. All data from Leach (1976).
8. All data in MJ/t.

Table 20 Support Energy for Horticulture in the UK

Crop	Vegetables	Glasshouse crops	Soft fruit	Vines	Top fruit
Fertilisers (N,P,K & Mg)	1937.3	400.5	112.5	1.7	545.3
Crop protection (Sprays etc.)	173.2	29.4	28.4	3.1	153.5
Irrigation	600.1	219.8	79.5	---	141.3
Mechanisation (Fuel, repairs etc)	1312.5	16.1	63.1	1.1	267.3
Heating (incl. CO_2 enrichment and soil sterilisation)	229.9	40345.1	---	---	---
Electricity	---	985.8	---	---	---
Crop support (wire, twine etc.)		56.0	29.3	0.5	---
Glasshouse (Depreciation and repair)	7.1	4408.3	---	---	---
Extras (Pots, growth regulators etc.)	---	37.1	---	0.1	---
Totals	4260.1	46498.6	312.8	6.5	1107.4

Notes

1. The vegetable data excludes watercress.
2. The glasshouse data excludes mushrooms, sweet peppers, forced rhubarb and roses.
3. All data from Morris (1983) drawn from Leach (1976) and MAFF (1982).
4. All data in TJ ($J \times 10^{12}$).

Chapter 3. A Comparison of Four Farm Studies on Energy Use.

3.1 Introduction

These have been chosen to serve as case studies against which the aggregated and tabulated farm energy usage data in chapter 2 can be compared. The studies are a mix of methods, farm type and sizes, both real and hypothetical. None are based on careful day to day observation of farm practice over a period of time, but are constructed from farm records, agricultural statistics and energy data published by MAFF, the Farm Electric Centre and similar bodies.

With respect to the hypothetical studies some care must be exercised in making comparisons as there is a possibility that similar sources have been used for both. Whenever possible in this study figures have been compared in such a way that there is little chance that they are based on similar or the same sources. However in this field of study, where data has been built up by a combination of methods ranging from direct observation to working back from national data, one can never be quite sure that the figures relating to the same usage have come from completely independent sources. The four studies will be considered in the order in which they were completed.

3.2 Downs (1974)

The first to be considered is of three dairy farms which are:-

Farm A. An actual farm of 75.5 ha. with 100 cows which is described as small unintensive.

Farm B. A hypothetical farm of 48.6 ha. with 100 cows and described as small intensive.

Farm C. A second hypothetical farm of 145.7 ha. with 300 cows described as large intensive.

The hypothetical farms have been constructed from data published by MAFF, FAO, ADAS, the Farm Electric Centre and a number of independent research studies including Leach and others from the University of Reading from where this work originated. The object of the study was to investigate the effect of intensive techniques (i.e. the use of use of chemical and energy inputs) and scale (i.e. farm size) on production efficiency (i.e. energy per unit of milk) on dairy farms. For the sake of the study the system boundary was considered to be the whole farm but the writer realised the problem in seeking to set precise boundaries in a system where energy inputs come in a number of forms and from a number of different sources.

As all the farms were dairy, certain assumptions could be made, such as that all farms existed for the production of milk only, stock replacements were reared on farm and all milk sold in bulk to dairies. The major components of support energy in milk production were calculated for the three contrasting systems in terms of energy per gallon of milk. Other figures such as energy for barley and hay production were also calculated as well as the energy input per hectare for the whole farm.

The study showed that broadly speaking an increase in farm size enabled economies of scale to be realised which in turn produced an increase in the efficient use of support energy. However, an increase in farm intensity had the effect of reducing the efficiency of support energy usage. The fall in efficiency with increased intensity was largely due to the heavy support energy component in artificial fertiliser production; a second stage of the investigation was completed to consider methods by which fertiliser support energy could be reduced.

It was therefore concluded that the most efficient form of dairy farm was large and non-intensive, but the limited nature of the study prevented any conclusions on the optimum levels of intensity and size for maximum efficiency to be achieved. Energy inputs in the study were calculated in terms of kcals. per gallon, pound or acre as necessary. In order to be able to make comparisons with other studies these data have been converted into GJ per kg. or GJ ha. and appear on table 1 together with data from other studies.

3.3 <u>Pimbert (1978)</u>

The second of the four was conducted after the publication of Leach (1976) and probably inspired by that work. As the title indicates, the study is an attempt to compare the energy intensiveness of two dairy farm types (organic and conventional) during the year 1977. Some attempt was made to match the variables in the organic and conventional farms, but time and other limitations prevented this from being any more than a match in respect of certain variables linking the four farms.

Data was collected from farm records and through personal contact with the respective farmers. In addition to Leach, earlier workers such as Stansfield, Slesser and Blaxter were drawn upon to provide basic energy data on farm operations, as well as the energy components in inputs such as fertilisers and concentrates.

From the basis of 25 basic energy budgets for grass, on-farm animal feeds and other inputs, larger budgets for hay and milk production were produced. In common with the Downs study (refered to previously) it was observed that the main difference between the energy inputs could be largely accounted for by the support energy in fertiliser production. The figures given in the table have been drawn from various points in the study to represent as far as possible the range of data produced.

Pimbert observed that the results can used only as indicators of the energy differences between organic and conventional farms. Limitations on farm matching, lack of full farmer co-operation and the need to construct energy budgets from secondary data prevents anything more than this.

3.4 Thompson (1984)

The third study is a comprehensive work based upon three large farms, two of which form part of the University of Reading estate. The farms are:-

a) Churn Estates, Blewbury, Berkshire of 700ha. growing wheat, barley, peas, kale and lucerne. The farm also undertakes ewe breeding, beef fattening and rears intensive pigs.

b) Strattons, Kingsclere, Hampshire of 230 ha. growing winter cereals, oats and pasture for cattle rearing and fattening.

c) Sonning, Reading of 203ha. growing grass and feed for 294 dairy cows.

The objective of the study was to investigate whole farm energy usage and identify new technologies which could be used to improve energy usage or increase efficiency. A secondary objective was to produce a computer model of each farm's economy to test the effect of new technologies on each farm. Data was taken from farm records, and relevant research articles; other data was obtained from slurry and manure production and the fuel used in tractors and harvesting equipment.

Apart from energy usage data other objectives were to discover:-

i) the economic conditions under which energy saving technologies might become viable,

ii) the energy potential of manures and crop wastes,

iii) the potential for energy saving through the efficient use of nitrogen fertiliser and animal feed.

In this study the mix of data from farm records, published works and new surveys is good enough to count as work which can be considered to be essentially original and thus useful for making comparisons with other studies. The data produced on energy usage for a number of crops and animal requirements are listed in table 1. In order that cross comparisons can be made between the Thompson study and data in this research report, the Thompson data given as energy per head for beef, sows and pork has been translated into live weight using material from chapter 2 (Spedding 1983) on national farm energy inputs and compared with the farm stock sales figures published in *Farmers Weekly*. These are presented as Appendix 1 and show that a far agreement exists between the calculations based on the Thompson and Spedding data when compared with published national figures on the live weight of farm animals.

3.5 <u>Page et.al. (1985)</u>

The final work for comparison with national farm energy data is based upon data all of which has come from either the electricity industry or MAFF. The objective of the study was to investigate the viability of wind generators on farms to produce electricity both for farm use and to export under the terms of the Energy Act (1983). This Act allows for the private generation of electricity both for the use of the producer and for sale to the local electricity authority via the National Grid.

The study constructs eight hypothetical farm types from which a general model of electricity usage is produced. The eight farm types are:-

(a) three poultry farms one each small, medium and large

(b) one large dairy farm,

(c) three glasshouse "farms" one each small, medium and large

(d) one large pig farm.

Scenarios were produced for each farm in terms of type and size. From these scenarios profiles of electric power usage were constructed according to the month and day and if necessary, time of day.

Five wind generators ranging in size from 10kW to 100kW were chosen as being suitable for farm application. Actual or estimated generator costs were obtained together with the annual energy production of each machine using power/wind speed characteristics and wind speed/duration curves for certain specific sites. Two mean annual wind speeds of 5.5m/s and 7.0m/s were chosen for test purposes and hourly mean energy production profiles obtained for a whole year.

Four geographical regions were chosen as agricultural concentration areas, namely SW England, NW England, S Wales and S Scotland and the electricity tariff structures of the relevant electricity boards obtained. The output of each generator was matched to electricity usage on an hour by hour basis and overall cost figures produced taking into account extras such as installation, metering, running and maintenance costs. A comparison was obtained with similar farms where generators were not used and the profitablity calculated based upon a sinking fund rate of return approach.

Nearly 1000 farms of the types considered were identified as giving a rate of return of more than 5% based upon the above models and data. It was recognised that this number is very sensitive to tariff considerations and generator costs; a tenfold increase in the number of farms could be obtained if the electricity purchase price was equal to the unit supply price and the price of generators fell by 30%. Developments in generator production and sales since this study was completed is such that this 30% fall has been reached and in some cases, exceeded.

3.6 The Tables - a Discussion.

Table 1 shows the energy inputs and calculations from the four studies together with data taken from other sources for comparison. These data are for arable crops; table 2 shows similar comparisons for livestock and animal products. These comparisons form the total of those which it is possible to make with others available from national studies where calculations are of a general rather than specific nature. With the exception of the translated Thompson data (already refered to), figures in the four studies which rely on data from the reference studies have been omitted.

Table 1 shows that in spite of the different sources, methods, dates and farms from which these data have been obtained, there is broad agreement between the four studies and the aggregated data in chapter 2. The cases where large differences exist between the studies and the reference figures can broadly be accounted for as follows. The Pimbert data for oats and kale were derived from organic farms where the use of little or no inorganic fertiliser could easily halve the energy input.

The hay and lucerne silage data for the Thompson study are both somewhat higher than either of the other studies and the reference figures; this could also be accounted for by the generally higher fertiliser input level in the Thompson farms when compared with the national average as well as the relatively small areas of the respective farms which were used for these crops. However, there does seem to be an abnormally high energy input into lucerne silage production at Sonning considering that no N-fertiliser was used; this may be due to some other requirement such as drying.

A similar picture of general comparablilty can be seen in table 2. The difference in the heifer data is due to the Pimbert data being for a one year beast only whereas the Leach data was for two years. The eight hypothetical farms of the Page study stand up well when compared with the reference data. Thompson also demonstates that the distribution of support energy through the various farm inputs bears comparison with White (1981) as given in table 1 of chapter 2. His estimates for support energy in the fieldwork activities of ploughing and harrowing compare well with earlier work and are shown in table 3.

3.7 <u>Conclusions from the Four Studies.</u>

Few published studies of this nature exist hence it was not possible to choose four selectively in order to ensure adequate cover of their form and data. Nevertheless these farms, real or hypothetical, span a period of ten years or so, are based upon real data from farms some 200 miles apart, range in size from under 100 ha to 700 ha and are subject to a variety of management regimes. It can therefore be said that they reasonably represent a wide range of activitities in farming and can be taken to indicate, with some measure of confidence, the spread of use of energy which takes place on the farm.

These data from the studies are mix of measurements taken on farms, farm records, farm impressions and the development of earlier published data from a variety of sources. It is not possible to determine to what extent these data have a common root although some of the material must originate from the other individuals and research groups associated with studies in this area. In spite of this the nature of these four studies is such as to give sufficent grounds for believing that these data produced are sufficiently original, diverse and reliable to form a fair comparision with the national data displayed in chapter 2.

In the light of the above it is therefore safe to say that given the usual allowance which must be made in an activity so diverse as farming, the figure show a fair level of agreement with the national data and support the claim that they indicate the true level of energy usage in farm activities of one kind or another. It was not possible to compare many of the figures in these studies with the national data presented in the tables of chapter 2, but given the level of agreement with those which were possible it is reasonable to assume that comparability would be found with others also. It can also be concluded that these data vary but little in the UK when distance, farm size, manangement regimes and date of study are considered.

It thus follows that it is safe to use these data as a basis for further studies in this area in order to determine cost and energy alternatives or develop strategies by which this energy can be conserved. It must be remembered that the actual monetary value of the energy used in any operation is not the most important determinant where policy or prices are at issue. The main constraints are elsewhere in the human and institutional domains as later chapters will reveal.

Thus any strategy designed to bring about a change in energy policy, prices or usage must largely rely on non-technical factors such as attitude, incentives and institutional change. It is to these factors that this study must eventually turn and in so doing bring it towards other works which seek to achieve a similar purpose in other areas of energy usage.

Table 1 Comparison of the Four Studies and References for Plant Crops

Study	Downs	Pimbert	Thompson	Page	<---Reference---> Data	Source
Crops						
W. Barley	13.5	13.9[3]	21.2		17.6	a
W. Wheat			25.2		18.9	b
Oats		8.22[4]	14.9		15.7[5]	b
Hay	6.8	8.09[3] and 11.6	17.3		9.5[1]	b
Silage						
grass		23.5[3] and 25.1	24.2		27.8[2]	c
lucerne			17.0		8.8	c
maize			13.9		18.8	c
Kale		5.26[4]			10.0	c
Peas			11.4		10.4	b
Rape		3.32[4]				

Notes

1. One cut and graze only.
2. With low N fertiliser input.
3. Data for the two conventional farms only.
4. Data for an organic farm.
5. This is an average of a number of figures.
6. All data in GJ/ha.

Sources

a. White 1981
b. Leach 1976
c. ADAS/NFU 1981

Table 2 Comparison of Four Studies and References for Animal Products

Study	Downs	Pimbert	Thompson	Page	Reference Data	Reference Source
Product						
Broilers				10.3	12.0	a
Cows (a)			33.1		30.0	b
(b)				2.36	4.4[1]	c
One yr. heifer		5.3[2]			14.6[3] to	b
		9.54			21.0	
Sheep			16.2		10.1	d
Sows			350[4]		40.0	a
Beef			370[4]		45.0	a
Pork			62[4]	48.4	32.0	a
Eggs				32.3	58.0	a
Milk (a)		19.4[5] and 28.9			31.0	b
(b)	4.2	4.4[5] and 6.72			6.0	c
(c)	24.2	16.3[5] and 32.8			32.5	d

Notes

1. Page data and corresponding Morris reference for electricity only.
2. Data for conventional farms only.
3. Reference data for two year old heifer.
4. Calculated data; see Appendix 1.
5. Top figure is the average of the two organic farms and the bottom figure is the average of the two conventional farms.
6. The units are as follows for:-
   broilers, MJ/bird; cows (a), GJ/kg; cows (b) and milk (a), GJ/cow; heifers, GJ/beast; sheep and milk (c), GJ/ha; sows, beef and milk (b), MJ/kg; pork, MJ/pig; eggs, MJ/hen.

Sources

a. Spedding 1983
b. Leach 1976
c. Morris 1983
d. White 1981

Table 3 Comparison of the Thompson Study on the Churn, Stratton and Sonning Farms with References for Fieldwork Operations

Study	<-----Thompson----->		<-----References----->	
	Farm	Data	Data	Source
Operation				
Ploughing	Churn	727)	654)	Stansfield (1975)
	Strattons	1296)	840)	Leach (1976)
	Sonning	840)		
Harrowing	Churn	289	235	Stansfield (1975)

Units

All data in MJ/ha.

Chapter 4 The Conservation of Energy on UK Farms

4.1 Introduction

In common with all users of energy, opportunities to consume less by employing conservation techniques exist on UK farms. Apart from the employment of common techniques such as insulation, heat recovery and electronic control, there are areas of farm practice where more specific techniques can be employed. These techniques can be divided into two broad groups, namely those which are local and generally related to on-farm energy usage and those which are wide scale and relevant to overall farm practice or the use of off-farm energy. Table 1 shows examples of these two groups.

Table 1 Local and Wide Scale Opportunities for the Conservation of Energy on Farms

Local	Crop drying techniques
	Machinery usage
	Glasshouse heating
	Feed and fertiliser usage
	Heat recovery in the dairy and intensive animal housing.
Wide Scale	Organic farming techniques
	Plant development
	Power station waste heat utilisation .

As this study is centred on the application of alternative energy techniques on UK farms, most of this chapter will be devoted to the local rather than the wide scale energy saving opporunities. A number of research projects have been pursued towards reducing energy usage in these areas and these will be discussed. In the wide scale group, organic farming and plant development are primarily aimed at improving or maintaining crop yield whilst reducing or eliminating the use of inorganic fertiliser.

It has been show that reducing fertiliser use, particularly N fertiliser, can save more energy than any other method in modern farming. The Downs, Pimbert and Thompson studies (discussed in chapter 3) on the use of energy on specific farms, have drawn attention to ways of reducing fertiliser input with significant results. Waste heat utilisation is usually taken to mean the use of reject heat from power stations (or other large energy users) for ground warming and glasshouse heating and is outside the scope of this study.

4.2 Crop Drying Techniques

Some crops need to be dried after harvesting in order that the moisture content is reduced to a level which will prevent deterioration during storage caused by disease or infestation. The most notable crops which are dried are cereals and fodder which have to be stored for some months, and frequently to keep through periods when the weather is such as to accelerate deterioration. Techniques are employed to dry crops as quickly as possible and maintain this level of dryness at a given temperature until the crop is taken for use. For grain drying the quantity of energy required per tonne of crop can vary considerably depending upon the drying method, the temperature and humidity of the air and the amount of moisture held by the crop at the start of drying.

The energy required to dry cereal grains to a 15% moisture content lies between 324 and 648MJ/tonne (Gibb 1975). According to the Leach data given in chapter 2, between 41 and 64MJ/tonne is required for each 1% of moisure removed which suggests that on average drying is required to reduce the moisture level by about 10%, that is from 25 to 15%. Under worst conditions moisture content in grain is about 25% with an average of between 18 and 19% so the difference could be due to the level of efficiency of the various drying techniques and devices which are available. The average energy requirement for 'green' crops such as grass and lucerne is considerably greater at about 7,000MJ/tonne of dry matter (White 1980). Hay drying (presumably after initial drying in the field) varies from 324 to 1630MJ/tonne (Leach 1976).

Drying is achieved by blowing air through the crop until the desired level of dryness is achieved. The air itself may be both dried and warmed before use and fan assisted throught the material. Ways of reducing the energy required for drying are as follows.

(a) The design of crop drying equipment with energy efficiency in mind.
(b) Careful use of drying equipment.
(c) Making use of unheated air by choosing to dry when the weather conditions are favourable.
(d) Close control of the temperature and humidity of the air.

(e) Conditioning of the air making use of the heat pump cycle rather than simple air heating.

(f) Employing renewable energy sources, eg solar; straw and wood as fuel.

(g) Recovery of the heat from the exhausted air.

(h) An even distribution of the air through the crop when drying.

Dryer design was compared in a study on the mixed flow and crossflow types. In a continuous performance study it was observed that in terms of MJ/kg of moisture removed the mixed flow type was the more efficient. When the air used for drying was recirculated it was found that the saving in fuel was almost proportional to the percentage of air recirculated up to approximately 25%. Thermal efficiency remained more or less constant at about 6MJ/kg for levels of moisture reduction from 1 to 7%, but the efficiency improved to 4.5MJ/kg as the drying air temperature was raised from 40 to 110°C (Bartlett 1981).

A Danish development in dryer design using the heat pump cycle to condition the air was shown to reduce energy demand by almost 50%. Incoming ambient air is first cooled by the condensing coils raising the relative humidity to 100% and releasing moisture. The evaporator coils then raise the air temperature above the ambient level; this is mixed with a fresh supply of ambient air to produce the correct mix for drying. The whole system is controlled and monitored by computer; a bonus is that by this method the grain can be dried at up to three times the normal depth of crop, saving in floor space and the capital cost of the drying house. Although the payback time in energy saved is quite long (about 10 years) the advantages of faster drying, closer control and reduced floor space bring extra savings which make the equipment worth while (Butterworth 1985 & Far. Wk. 1986b).

Using straw as a fuel has enabled two farmers to reduce the cost of their drying operations. Straw is burned in a furnace and the hot air produced is used to warm the fresh air fed to the dryer. This method enabled the two farmers to not only reduce their fossil fuel consumption but also cut the cost of drying to less than 20% of that previously (Fuller 1983).

The quantity of energy required per tonne of green crop dried can be reduced by wilting the crop before drying. A crop with an initial water content of 80% to be dried to 10% can lose up to 75% of this water by wilting (Gibb 1975). Average fuel savings of 30% can be achieved using this method (ADAS/NFU 1981).

4.3 Machinery Usage

Up to one half of all petrol and diesel oil comsumption on farms can be attributed to the use of agricultural equipment, mainly tractors and haulage appliances. This is about 25% of the on-farm energy use, that is not counting energy for activities such as fertiliser and machinery production. Research projects aimed at finding ways to reduce this energy fall under three broad headings. These are activities concerned with:-

(a) machine choice, action and maintenance.

(b) fieldwork activities such as ploughing.

(c) field size and field layout.

4.3.1 Machine Choice, Action and Maintenance. Up to 20% extra fuel can be consumed if the machine is not matched to the task it is performing. As farmers cannot be expected to own tractors which match every task, it has been suggested that hiring, contracting and sharing arrangements could be employed to match machine to task as much as possible (ADAS/NFU 1981). Farm trials carried out by the National Institute of Agricultural Engineering (NIAE) in the 1950's and 1960's and reported in this study, show that regular maintenance could raise power output up to 10% in the course of a year. Equally important is regular maintenance of ploughs, harrows and other equipment with appropriate attention to knives, tines and shares as necessary.

Tractor wheel slip is a frequent source of fuel wastage, especially in wet weather. An American study into tractor slip showed that it depends on the pull/weight ratio, the type of soil and its condition and whether the drive was via tyres or track (Taylor 1977). Farmers need to choose the optimum condition for tyre loading to secure grip without raising the tare weight unecessarily. Track drive was better than tyre for adhesion; also better grip was obtained if compaction could be kept to a minimum by reducing runs over the same piece of ground. For tyre driven tractors it is claimed that bolt-on gripwheels can improve traction by as much as 340% on muddy ground (Cameron-Gardner 1985).

4.3.2 <u>Fieldwork Activities.</u> Improvements in tractor fuel efficiency have been obtained by changes in ploughing equipment and techniques. Results from a study on tropical soils (which are likely to be equally relevant to European soils) showed that the chisel plough used 40% less energy than the mouldboard plough. Other techniques such as shallow sweep, disc and precision strip tillage all used less energy (Willcocks 1981). A reduction in yield using the sweep technique caused the ratio of energy per tonne of grain to be higher than for mouldboarding, but other methods all saved energy per tonne of grain produced. A study in the United States showed that other techniques such as direct drilling, reduced tillage and no tillage systems gave energy savings of about 40% without a corresponding fall in yield (Vaughan 1977). Nearer home, trials conducted by the Scottish Institute of Agricultural Engineering (SIAE) gave similar results (Pidgeon 1979).

Apart from the tractor, energy saving can also be obtained in other items of agricultural equipment. For example, a study on the development of the combine harvester has shown that if harvesting could be limited to stripping the grain from the wheat leaving most of the stalk standing in the ground, the combine could not only work 80% faster but a considerable energy saving would result (Klinner 1987). Promising though such techniques may be it may simply transfer energy use elsewhere; in this case it may be necessary to use more tractor energy to harvest or plough in the wheat stalks or more N fertiliser may be necessary to break down the additional material returned to the soil. Similiarly, although single pass, direct and reduced tilling systems save on tractor fuel they may require greater inputs of herbicides and fertilisers to maintain yields thus taking energy from elsewhere. Reduces yields may cut the farmers' income far more than reduced fuel costs will save, thus making the systems uneconomic.

4.3.3 Field Size and Layout. Turning to field size and shape, farmers are now able to consider designing fields to suit their equipment and this can have the attendant advantage of reducing energy requirements. The large field now common in cereal farming, although criticised because of the loss of hedges and possible topsoil due to erosion, can help to save energy; when the field length is less than 200m the amount of fieldwork energy/ha rises significantly because of turning requirements. On the other hand when new fields are being constructed care in relation to contour and the amount of levelling and fencing required can save both in constructional and fieldwork energy. A balance needs to be struck between the high fieldwork energy needed where minimal attention has been paid to layout and the high constructional energy requirements for extensive levelling although this will reduce the fieldwork energy necessary later (Willcocks 1981).

Larger fields enable different forms of crop cultivation equipment to be used and one example of this is the gantry system. The "Dowler" gantry system consists of a 12m long steerable truss upon which the control cabin is mounted; the advantage is that the equipment can be confined to specific "tracks" on the land avoiding compaction and reducing the number of passes necessary. In addition to the advantages of reduced time and soil damage, energy savings of at least 50% have been claimed (En. Man. 1988).

4.4 Glasshouse Heating

There is about 1400ha of heated glasshouses in England and Wales, that is some 72% of the total of protected crops under glass. In 1984 the cost of this heating lay between £3 and £5 per m^2 representing 20 to 40% of growers' production costs (En. Man. 1984). As the most energy demanding sector of agriculture there has been, since the 1973 oil price rise, considerable incentive to conserve. With oil still the most common fuel for glasshouse heating, conservation efforts have considerably reduced glasshouse oil consumption from the 1973 peak of 550×10^6 litres. A number of techniques have been developed over the years to enable glasshouse energy demand to be reduced. As a result of the application of these techniques energy usage in the glasshouse sector has fallen by about one third of its 1973 level. These techniques include:-

(a) Plastic thermal screens to reduce night heat loss.

(b) Double skin plastic envelopes.

(c) Reduced air loss by sealing glass panes and entrances.

(d) Reduced air temperature accompanied by root zone warming.

(e) Heat recovery by dehumidification or when air changes occur.

(f) The use of heat pumps.

(g) Closer control of air temperature and heating appliances.

(h) An integrated approach based upon an overall design strategy to reduce energy consumption.

(j) Environmental factors such as the use of wind breaks and the orientation of glasshouses.

4.4.1 <u>Screens and Glazing</u>. Plastic film thermal screens reduce night heat loss by acting as an impermeable layer between the crop and the glasshouse envelope. This reduces heat loss by convection, and latent heat will only be lost if the film temperature is lower than the dewpoint of the air surrounding the plants. Radiation loss is also reduced; the screens can be withdrawn during the day when light maximisation is necessary. As most of the heating is required at night to maintain a temperature of 17°C or so, considerable energy saving is possible. Thermal screens have been shown to reduce loss by up to 40%. Various materials have been tried for the screens and depending upon the wind speed, thermal transmittances in W/m^2K has been reduced to 40% of the value of earlier materials (Bailey 1979).

Early attempts at double glazing, although effective in cutting heat loss, were rejected because of the associated loss of light. This loss, which depending upon the material and number of sheets can be as much as 20%, can reduce or delay cropping leading to an unaccepable fall in revenue. More recent developments in glass and "bubble" polythene have reduced this loss and double glazing has had the additional benefit of reducing air loss through joints and where CO_2 enrichment is employed. Light transmission of up to 98% of the original has been reported (Sims 1982). Light loss can be offset by allowing the glasshouse temperature to rise; a 1°C rise can compensate for light loss of 10% but this may be such as to increase the overall energy requirement rather than reduce it (Cockshull 1986)..

Fuel savings have enabled smaller heating plants to be installed offsetting the cost of the plastic. The two principle plastic materials in current use are poly-methyl-methacrylate (more popularly know as acrylic) and polycarbonate. Although good crop yields have been reported, some crops are affected by the presence of plastic and there is a tendency for drops of condensation to hold on to the plastic thus further reducing light transmission (Sims 1982). If the walls are only partly lined with double skin plastic, light loss can be reduced to 1½% and the vertical positioning of the material prevents the settlement of water drops.

Another approach to overcoming light loss due to double glazing and thermal screening is the use of prisms. Using prismatic and reflecting louvre techniques light gains of up to 30% have been achieved in experiments conducted in both Britain and Europe. It has been suggested that modifications to existing glasshouses can be made such that improvements of up to 50% light enhancement can be achieved (Critten 1985 & 1986).

4.4.2 Root Zone Warming. A completely different approach to the problem of glasshouse heating is the technique of root zone warming (RZW). It has been found that if the night air temperature is allowed to fall to 5°C (instead of the more usual 16°C) and at the same time the roots are held at a temperature above 16°C, long term crop yields can be maintained with substantial energy saving. An Irish study showed that although early tomato yield fell from 8.3 to 6.0kg/m^2 of floor area when

RZW was employed up to 31 May, after this date an average yield of 21kg/m^2 was maintained up to 31 August (O'Flaherty 1982).

Unfortunately the estimated £15,000/ha (£1.5/m^2) fuel saving using RZW was just outweighed by the loss of gross returns due to the fall in yield in the early part of the season. Root warming can be achieved using underground pipes to carry hot water or other substance and switched on and off as necessary. A combination of double skin plastic and RZW has been shown to reduce oil consumption from over 50 litres/m^2 to 20 litres/m^2 for tomatoe production showing considerable scope for energy saving. The main drawback is the large capital investment needed to achieve these reductions (Elect. Rev. 1987a).

4.4.3 <u>Heat Pumps</u>. Heat pumps have been used in glasshouses as a means of saving energy or to provide heat for RZW or dehumidificaton. A very comprehensive study of the topic suggested that the largest reduction in glasshouse heating costs was achieved when the heat pump was sized to provide 60% of the total energy requirement (Bailey 1982). This arrangement requires a secondary heating system to operate in tandem when maximum heating is required, but a saving is obtained when the capital cost is optimised. The scheme was financially viable for all fuels apart from 3500sec. oil when the study was conducted.

This bivalent arrangement of heat pump plus conventional heating system can operate in the air to water, air to air, water to air or water to water modes as convenient. Heat can be taken from ground water or a nearby stream and where the opportunity exists, from a source of industrial waste heat. The heat can be distributed using the same pipes or ducts as the conventional system or an entirely separate distribution system be used. Alternatively the output from the heat pump can be used for RZW using small bore polythene piping.

Another use of the heat pump cycle is to operate it as a dehumidifier to both control the level of humidity and recover the heat which would otherwise be lost in condensation on the glasshouse enclosure. Heat can then be recycled from the moist air to the roots or as dryer and warmer air lower down the air space of the glasshouse. With about 25% of heat lost through latent heat transfer to the enclosure, there is plenty of potential for heat recovery using dehumidification.

Researchers tend to agree that the best approach to the use of heat pumps is to consider the integration of various conservation methods together with heat pumps as a total package (Smith 1982a and Weir 1982). Such a system is the SCIRAY development of the ICI Research Station, Fernhurst, Surrey (Turbard 1982). This is essentially the glasshouse equivalent of full building energy control employing a computer. In a specially designed sealed glasshouse with double skinned plastic cover air conditioning, humidity control, heat recovery, thermal storage and a computer to select from a choice of twenty eight control strategies depending upon ambient and glasshouse conditions were used. The nett result was a 50% saving of energy with a corresponding smaller primary heating facility obtaining water as a by-product which can be used for irrigation. The main drawback is the heavy capital cost for what is essentially a completely new glasshouse heating system.

A similar system using a conventional glasshouse structure with double skinning and night blinds is also possible. This all electric system employs a heat pump/dehumidifier with heat recovery and night storage facilities as before. With a capital cost of £40,000 and energy saving of nearly £15,000 p.a. this gives a simple payback time of 2.7 years (Dodson 1983). Any savings in all electric heat pump systems which are supplied from the National Grid are necessarily offset by the large losses in the power stations. Although not strictly a concern of agriculture as such, this could be overcome if the supply was gained from a CHP system or some renewable source such as wind or photovoltaics.

4.4.4 Computer Control. More recent developments in glasshouse heating has been with the intention of achieving commercial viablility using computer control and light enhancement. One such is the use of PVC panels and double skin polythene covers which produce savings of between 30 and 40% at a capital cost which can be considered economic for most commercial growers. Another is the use of liquid foam or poythene pellets which are used to fill the space in double skin glasshouses. This enables night thermal screening to be automatically accomplished promising to reduce peak heat requirement by 90% and could give a payback time on investment of under two years (O'Flaherty 1985). A computer study of terraced glasshouses for pot plants suggested an energy saving of about £10/m^2 compared with standard frame glasshouses without loss of light or plant yield. These glasshouses had other advantages such as reduced internal volume, protection from northerly winds, ease of internal screening and thermal storage on the north facing rear wall (Hare 1985).

Probably the ultimate in glasshouse energy conservation and control is in the recently opened nursery in Stockport. Full computer control is used to supervise the gas condensing boilers, root zone warming, flue heat recovery, air temperature, CO_2 enrichment, humidity, light, air flow, irrigation and thermal screening. The glasshouse complex is highly insulated and virtually double glazed throughout. The nett result of all this is that operating costs have been cut by £150,000 from the earlier nursery, average plant growth times have been cut by one third and the number of plants lost cut by one quarter. Not all of this financial saving is from reduced energy usage, but here is a good example of the level of control which can be achieved using the latest techniques in a fully protected environment (Nat. Gas 1989).

4.5 Feed and fertiliser Usage.

Although the on-farm production of feed may save the farmer having to pay the labour costs of the feed manufacturers, he is unlikely to be able to match the same level of energy efficiency as a bulk manufacturing plant. Any saving to be had are likely to come from a reduction in transport energy; it has been claimed that savings in transport energy can be such as to pay for the farm milling equipment in two years (Wakeford 1980) but this ten year old study may reflect the relatively higher energy costs prevailing at that time. Farmers are more likely to turn to feed production as a means of using their own feed material and making it up in accordance with their own formula than with energy saving in mind.

A more promising area for energy saving is in the use of fertiliser on the land. It is well recognised that farmers have been increasing their use of N fertiliser over the years and that this has become a point of concern for environmentalists (Addiscott 1991). Farmers themselves have been advised that they could use less fertiliser without suffering loss of yield and income. An ADAS study showed that about three quarters of the sample of arable farmers were using up to 200 kg/ha more fertiliser than was necessary for full plant take up suggesting that a saving of £240/ha in fertiliser costs was possible (Chalmers 1988). Thus careful use of N fertiliser in timing as well as in amount will be of benefit to both farmers and the environment although fertiliser manufacturers may see it somewhat differently.

4.6 Heat Recovery in the Dairy and Intensive Animal Housing.

The opportunity which exists for energy conservation in the dairy is due on the one hand to the need to cool milk for storage and on the other to produce hot water for udder washing and general cleaning purposes. Without any attempt at conservation, about 27% of the dairy energy take is used for milk cooling, 40% for general cleaning, 14% for vacuum pump operation, 9% for lighting and 6% for udder washing. Space heating (which is usually kept at a low level) and miscellaneous requirements account for the rest (ADAS/NFU 1981).

Heat recovered from the milk can go towards the energy required for cleaning and washing. Energy can also be recovered from the vacuum pump; claims of up to 70% savings in water heating costs have been recorded using this technique. Milk heat is recovered in a heat exchanger unit which is coupled to the vacuum pump and used to supplement the heat given to the water from conventional sources. Sufficient may be recovered to make extra heating unnecessary; temperatures in the range 54 to 76°C have been achieved using these heat recovery units (Far. Wk. 1984).

The heat pump is an ideal device for recovering energy from milk and transfering it to washing and cooling water. Milk has to be cooled from 35 to 4.5°C for storage and this temperature range enables a high coefficient of performance (COP) to be obtained on the heat pump. Thus not only is heat recovered but at the expenditure of only 25% or so of "new" energy with which to drive the pump. Cold water can be heated to between 40 and 50°C by this method, the actual temperature depending upon the volume of water required and its initial temperature (Belcher 1982). Trials using milk heat recovery techniques have enabled energy demand for dairying to be reduced from 400kWh/cow-year to between 200 and 350 (Bowes et. al. 1981) but doubts were raised whether this level of saving, even at a time of high energy prices, was sufficient to pay for the capital equipment in a reasonable time (Wakeford 1980).

Heat pumps have also been used in other farming activities where the heat generated normally goes to waste. Two examples are in pig and broiler chicken production; heat is normally lost with the air which is expelled in ventilation. For pig production extra heat is required during the early weeks of life of a litter (up to 85°C) and this can be expensive to produce by conventional means. One broiler farmer claims to have reduced his heating requirements by 2p/bird using heat pumps (Gainsford 1984). Again with this kind of duty heat pumps are able to work with a high COP and therefore require a relatively low input of new energy to achieve the recovery. The reclaimed heat is imparted to the fresh air being drawn into the piggery or broiler house.

4.7 Organic farming.

Organic farming is not strictly a technique which is employed to conserve or generate energy on the land, but it is claimed that it saves energy as a consequence. Organic farming is the system based on the use of organic materials for the fertilisation and protection of crops as distinct from the use of inorganic materials which is common to other farming systems. Energy saving is achieved because:-

(a) no off-farm energy is used in the manufacture of fertiliser and pesticide material.

(b) less on-farm energy is used to transport agrochemical material over the land.

(c) methods of weed control tend to be labour rather than energy intensive.

On the other side of the organic balance sheet more energy may be used if tractors and other equipment are used for mechanical methods of weed control. Somewhat lower yields frequently result from organic methods and this may offset the savings if a larger acreage of land has to be employed to maintain the same level of output. However, lower yields does not mean that farmers will necessarily lose out financially as a result. The lower costs of farming together with the higher price which organic crops realise has enabled some organic farmers to maintain profitability even if their grain yield should fall from the more usual 7.5t/ha achieved by conventional farmers to the 5.6t/ha realised by organic methods (Gready 1988).

Studies in both the USA and the UK claim large energy saving benefits from the use of organic methods (Lockeretz 1977, Pimental et.al. 1983, Vine and Bateman 1981). The Pimental study claimed that energy savings over the range 29 to 70% were achieved depending upon the type of crop and method used. In the case of potatoes the result was lower energy efficiency compared with conventional method because of the greater losses due to disease and pests. The same was also true for apples, suggesting that on energy saving benefits alone organic methods are not necessarily the best choice.

Organic farming is increasing in popularity and should continue to do so now that MAFF is conducting its own trials. However organic farming is conducted for a variety of raisons of which energy saving is only one and probably well down the list of priorities. The main reasons will continue to be concern for the quality of food and the land, with energy saving an added bonus.

4.8 Plant Development.

Plant development can save energy in a number of ways. For example "new crops" can be developed which need less fertiliser, less water, are pest and disease resistant and require less working of agricultural machinery before and during harvest. All such developments will reduce the energy required per tonne of finished product and thus improve energy efficiency on the land.

Nitrogen fixing is achieved in some plants due to the symbiotic relationship which exists between certain soil bacteria, such that the bacteria receive some of the plant products in exchange for nitrogen. Apart from the well known nitrogen fixing plants such as peas, lupins and clover, researchers have had some success with rice and wheat and the search is on for nitrogen fixing systems which do not require the assistance of bactertia (Postgate 1987). In another area of research grasses are being developed which will tolerate lower temperatures. This will enable the growing season to be lengthened and hence reduce the amount of fertiliser which is necessary thus extending the time in which ruminants can be fed without silage and manufactured feed (McElroy 1988).

The other energy approach to crop development is the production of new strains and species which will release more energy on processing. This may be assisted by developments in biotechnology and bioengineering in other areas of study but as yet little work has been done to identify such strains and species. This awaits the time when there is greater pressure on the present plant population and the socio-enomomic conditions bring biomass energy to the fore in industrialised countries.

4.9 Conclusions

There is no shortage of ideas and technical solutions to achieve greater energy efficiency on the farm. As the examples and references given above have shown, for many of these the solution is relatively simple, the technology well tried and they are economically viable. Energy savings of 20% or so appear to be readily achievable in all sectors and for some savings of up to 50% or so are said to be possible. There are many examples of farmers who by force of economic circumstances or wider interest have persued energy conservation. However, although both money and energy can be saved there is still some way to go before the opportunities are fully exploited and as with all such opportunities, the greatest impediments to rapid take up frequently lie elsewhere. These will be explored in detail in chapter 6.

The Conservation of Energy on Farms - a Summary of the Data.

Sector	Aspect	Approx. Potential (%)
Drying	Dryer design	25 - 50
	Use of straw as fuel	20
	Wilting of green crop	30
Machinery use	Matching machine to the job	20
	Regular maintenance	10
	Reduce wheel slip	30
Fieldwork	Use of chisel plough	40
	Reduced tillage techniques	40
	The gantry system	50
	Field sizing and layout	(depends on situation)
Glasshousing	Screening and glazing	40
	RZW + double glaze	60
	Heat pump techniques	50
	Computer control	Over 50
Fertilising	Economy in use	40
Dairying	Heat recovery for water heating	50
Animal housing	Heat recovery	20
Organic farming	(Depending upon crops and methods)	30 - 70
Plant development	(At research stage)	(To be found)

References

See references given in the main text.

Chapter 5. The Potential For Alternative Energy Production on Farms.

5.1 Introduction.

Energy can be produced on farms by employing techniques and equipment which for purposes of categorisation can be divided into two quite distinct groups. The first of these, namely solar, relies on energy gained from the natural environment, notably the sun, wind, water and thermal gradients found in the sea or under the surface of the earth. As far as farming is concerned the only two of any consequence are the sun and the wind; the use of hydropower or the energy which can be obtained from hot (dry) rocks, although technically possible in specific farming locations, cannot be considered as very significant. In essence the solar panels, photovoltaic arrays and windgenerators which could be employed on the land are no different from those which could be use in the urban environment and as such can be considered side by side with them from the technical point of view.

The second group comes under the general heading of biomass. Strictly speaking biomass is the total of all organic matter, living or dead, upon the earth's surface, but in relation to energy generation it is taken to mean all organic matter (other than fossil fuels such as coal, oil and gas even though these are derived from organic material) which can be used for the generation of energy. Most organic matter can be consumed as food and 'burned' in animals and insects to generate energy and produce heat, and in essence the change which takes place in biological material to produce energy for man's convenience, be it in the form of solid, liquid of gas, is no different from that which takes place in the body. Whereas solar devices are no different whether they are used rural or urban environments, farming is particularly suited to to take advantage of biomass. It has both the land to grow the material and the space to do it at a volume which can make it worth while. Although biomass energy could be generated to some extent in towns (for example by using human waste to generate biogas) such enterprises tend to be either small scale or ruled out on social or environmental grounds.

Of the two groups, biomass energy is the most important and will be considered first. Currently biofuels provide about one seventh of the world's recorded energy requirements with and estimated annual production of around 2×10^{11} tonnes. In some countries of the Third World biofuel, largely in the form of wood and animal dung, can account for 90% of fuel needs (Flood 1983). In Britain and other industrialised countries biomass energy forms but a small part of the total energy take but is likely to feature more strongly in the future.

Although the burning of biofuels adds to the release of CO_2 which with other gases (in one combination or another) is said to contribute to the greenhouse effect, holes in the ozone layer and the production of acid rain, in the defence of biofuels the carbon so released came initially from the atmosphere only in recent years. This compares with the burning of fossil fuels the carbon of which has been locked up for millions of years and thus has not been part of the atmosphere since primeval times. Burning biofuels, event trees in age of 100 years, or so can thus be seen as part of the normal carbon cycle together with the decomposition of waste organic matter through natural processes.

5.2 Fuel Wood Production.

Fuelwood is a versatile fuel and can be used in a number of different ways. In the solid state it can be burned in stoves and furnaces as logs, chips, briquettes or dust. Alternatively it can be converted into liquid or gaseous fuel and consumed in boilers or engines. Compared with other natural biomass materials, wood is the densest and takes the longest time to grow to sufficient maturity for harvesting. Advantages are that after the initial years it does not require a great deal of attention and although the best returns are obtained from platations set on good lowland soils, it can be grown successfully in locations and on soils which would be regarded as unsuitable for other crops. For example, although fuelwood can be grown over much of the UK it is profitable on upland soils where it gives a better return than livestock (Carruthers & Jones 1983).

Currently the UK has one of the lowest areas of woodland in the European Ecomomic Community. Some 9% of the UK land surface is under wood compared with 27% in France, 29% in Germany, 31% in Spain and 32% in Portugal. Although some European countries have the advantage of lower population densities and climates which allow woodland to flourish at higher altitudes, these figure suggest that there is scope for a considerable increase in woodland area in the UK. Estimates of this increase suggest that the area of woodland could double beteween now and the early years of the next century (Hummel 1988).

Considerable research effort has taken place to determine the viability of wood as a fuel, covering variables such as the species of wood, planting and harvesting regimes, soil location, weed control, harvesting machinery, conversion technologies, environmental effects and the integration of energy forestry with agriculture. (See for example ETSU Projects 1987 -89 and Gready 1988). Cultivated tree plantations for short rotation energy forestry take two basic forms namely coppicing and single stem depending upon the variety. Coppiced varieties can be harvested between three and five years after planting whilst single stem trees are cropped after an interval of ten to twenty years. Coppiced trees can give yields of up to 20tDM/ha, sufficient to give an energy output of 400GJ/ha for Eucalyptus and Poplar varieties, with willow not far behind at 15 and 300 respectively. The estimated yield for single stem production of Southern Beech is much less than for coppice being 14 and 280 with Douglas Fir some way behind at 11.4tDM/ha and 228GJ/ha respectively.

Various estimates have been made of the potential UK crop on the basis of wood type and regime in relation to the prevailing price of conventional fuels, the availablility of grants and social constraints such as legal impediments to land use change. On the assumptions of a 5% discount rate, 60 year investment period, costs, revenues and prices constant in real terms, using existing land, agricultural and forestry grants and fuelwood valued at £36/tDM, the viable UK area of short rotation coppice woodland has been given as 0.09Mha producing 1.36MtDM of wood (Carruthers & Jones 1983). On the same basis modified conventional forestry could support 0.73Mha of woodland producing 3.32MtDM of fuelwood. These figures were shown to be very sensitive to small changes in the discount rate and the price of wood; for example it has been suggested that a 25% increase in price could raise the the area of viable woodland to ten times the above value. Current prices suggest that a potential increase in UK woodland area of between 0.82 and 2.26 Mha is possible yielding up to 4.6 tDM of usable wood for pulp, fuel and other purposes (Hummel 1988). All the above figures are subject to considerable variation depending on species, land fertility, harvesting regimes, prices and the extent to which the area of woodland is constrained by social and institutional factors.

Although woodland waste can be considered viable in some applications at the present time the production of fuelwood crops is a new and untried venture which still waits to be economically proven (Dept. of Energy 1987). Fuelwood in the form of chips can be used for glasshouse heating and one study suggests that chipped willow could cut energy costs by one third compared with oil (Hall and de Groot 1987). Woodchips can be turned into briquettes and marketted as an alternative solid fuel but like straw, briquetting machinery is currently far too expensive to make the enterprise viable (Staniforth 1982 and Roberts 1989). The technologies for the conversion of wood into gas and oil such as methanol and ethanol using pyrolysis and other techniques are either still in the experimental stage or although proven, are not as yet economically viable in Britain (Carruthers 1986).

5.3 Energy Catch Crops.

Catch cropping involves the use of land for energy production when it is not required for the production of food. The most suitable time is the period after harvest in late summer and autumn before the growing season is at an end. Typical plant species for catch crops are turnip, beet radish and kale but other species such as rape and nettle have been tried. The crop yield depends on the species and time of planting as well as local conditions such as weather and farm regime but up to 6tDM/ha is possible with an overall energy potential of about 4.5 Mtcepa (Bather & Carruthers 1981; ETSU 1985). The advantage of this technique is that it makes greater use of the land during the growing period of the year; the disadvantages are that catch crops could interfere with food crop production patterns and take labour and machinery from other farming activities which take place at this time.

Such crops have been planted in the past to extend the grazing season and provide feed for ruminants, but the technique could be exploited to generate material to produce energy. Catch crops do not displace existing crops, nor do they require great changes in agricultural practice. Using existing farm resources, they could increase farm income or reduce energy costs and be treated as opportunity crops not having to bear a proportion of farm fixed costs. The disadvantages are that catch crops would require extra labour, the yield is critically dependent upon the date of planting and such crops could be in competition with the practice of winter planting cereals.

Catch crop material can be used to provide feedstock for anaerobic digestion to generate biogas for on-farm use. With yields of 4tDM/ha necessary before costs are competitive with other fuels, biogas can be produced economically, but with catch crops currently worth two to three times more as animal feed energy catch cropping is not yet acceptable as a replacement. Morover the anaerobic digestion of vegetable matter is not so well advanced as for animal waste and an improvement of some 30% is necessary to make up the difference. There is also the problem, as with on-farm gas production generally, of matching supply to demand if gas storage costs are to be optimised (ETSU 1985).

Trials have showm that yields of over 6tDM can be achieved with crops which are sown in mid-July, but this falls off in a more or less linear fashion to about 1.5tDM for plantings in mid-September. From the point of view of yield the most suitable plant species for catch crops are stubble turnip, fodder radish, forage rape and mustard, but other factors such as speed of growth and frost resistance need to be considered when making a choice. Working within current constaints the potential UK annual catch crop production has been given as 21.94MtDM from 4.45Mha of land which should produce 213.9PJ of biogas or about 2.6% of 1981 UK primary energy consumption (Carruthers 1985).

5.4 Other Fuel Crops and Farm Wastes.

Apart from fuelwood and catch crops singled out for special mention there are a number of other species (such as beet, cereals and sunflowers) which can be specially grown or others (such as bracken, cordgrass and knotweed) taken from natural habitats. Agricultural wastes such as straw, potato and carrot tops can also be harvested for energy use. Some of these will be burned in the raw state to produce heat energy whilst others will be converted into liquid or gaseous fuels. If digested to produce biogas, green material can be expected to yield about 11.0 GJ/t. In the liquid form fuels which can be produced are ethanol, methanol and vegetable oil. Ethanol can be produced from crops such as wheat, sugar beet and maize and methanol from bracken. Vegetable oil can be obtained from oilseed rape, sunflower seed and soya beans.

5.4.1 Straw.

From the above list only straw is currently a viable crop for the production of energy for use either on farm or for use in industry situated in rural areas where straw is available. One estimate has put the level of straw produced in the UK at 17.8Mt with 10.2Mt baled for on-farm use, 6.3Mt burned in the field and 1.2Mt incorporated in the soil, but with the recent concern about straw burning these figures are likely to have changed (Larkin 1985).

Straw although light and generally scattered before harvesting can yield 14GJ/t when dry hence its common use as fuel for straw burning boilers. Many straw boilers used to generate heat or hot water are now in use on UK farms. This energy is being used to heat farm, green and livestock houses, dry grain and other crops and provide hot water for the dairy and other farm uses. Straw can be cheaper than oil for these purposes;

for example a 1.5MW boiler can offer a payback period compared with oil of between three and eight years (Martindale 1985, Staniforth 1982 and Phipps 1983).

In industry straw is cost effective compared to coal for small boilers, but to be cost effective with respect to oil larger boilers (i.e. greater than 4MW) are necessary. On the domestic market straw could have a place in the form of briquettes, but (as has already been mentioned) the capital cost of briquette making machinery rules this out under present circumstances. One analysis of the market suggests that the total consumption of straw as a fuel could exceed 0.75Mtcepa by the year 2000 (Martindale 1985) but this could change considerably in the event of a fall in cereal production resulting from a rethink of agricultural policy in Europe.

5.4.2 Cultivated Vegetable Crops.

All present methods of converting vegetable crops into liquid or gas are excluded on cost grounds, other than under special circumstances such as the high cost of conventional fuels due to geographical, economic or other reasons. Only as straight fuels for heat production were fuel crops viable and in this form in the early 1980's the cost of straw relative to conventional liquid or gaseous fuels was about 0.4 whereas for other materials the index ranged from about 1.6 to 2.0. (Carruthers & Jones 1983). Currently food production gives a better return than energy crops, and any attempt to grow energy crops rather than food could have the effect of raising food prices and thus further reduce fuel crop viability.

5.4.3 Natural Vegetable Crops.

Apart from cultivated crops it is technically possible to harvest naturally occuring crops such as bracken, cordgrass and knotweed for energy digestion feed stock. Yields of the order of 6tDM/ha/yr for bracken, 5tDM/ha/yr for knotweed and 16tDM/ha/yr for cordgrass are possible giving a combined energy potential of 27 Mtcepa (ETSU 1986).

The problem so often is harvesting; bracken frequently appears on steeply sloping hillsides and cordgrass on marshy soils, both difficult terrain for heavy machinery causing them to be far from competitive with conventional fuels (ETSU 1985). Some research effort is being made to improve the outlook for natural crops. For example, a selection of the normally tropical C4 cordgrass varieties are being successfully grown in England and Ireland with the potential of up to 40% more intercepted solar radiation into biomass than the C3 varieties in spite of the harsher European environmental and soil conditions (Jones et.al. 1987).

5.4.4 Animal Wastes.

Although dead or diseased animals could be counted as part of the total of animal waste on the farm, the only significant waste worth considering from the energy point of view is animal manure for use as biogas (methane) feedstock. Any manure will do, but that which is most likely to be available is from pigs, cattle and poultry; average gas yield which can be expected is about 5.7GJ/t of material. With the intensification of animal production on farms the disposal of manure has become something of a problem; spreading untreated manure on the land brings undesirable odours and other environmental problems and in Holland there is simply too much of the stuff to dispose of in any case (Armstrong 1988).

Thus farmers can turn to anaerobic digestion of animal wastes as a means of reducing or even eliminating environmental and disposal problems as well as for reasons of energy production. It is claimed that digestion can reduce the polluting power of raw slurry by as much as 80% and the digester residue is a storable and acceptable manure which can be used on the farm or sold as potting compost (Nielson 1977). One advantage of animal manure as energy feed stock is that in contrast to vegetable matter it is not seasonal; plans can be made to ensure that as far as possible it is available all year round. However the need for gas on farms is limited and seasonal; it could be used to produce winter heat for animal housing but otherwise the most convenient way to use it is for the generation of electricity and heat using combined heat and power plant.

As yet, heat and energy generation by this means is not economically viable per se, and farmers which have chosen to employ the technique do so for the packet of reasons given above. For reasons of capital outlay and animal stocking levels, it is also only possible on relatively large farms; for example about 300 breeding sows are necessary before it can be contemplated of farms specialising in pork production (ETSU 1986). Biogas production also requires the attention of skilled and dedicated staff who are more likely to be available on larger farms. The whole area of methane production has been quite well researched and numerous examples exist of trials and studies on digester design, feedstock and management regimes (e.g. ETSU 1986a & Roberts 1989).

5.5 <u>Wind Power.</u>

Wind power on farms today can be used for a number of purposes such as pumping water, generating electricity (either alone of in tandem with other equipment) and providing direct heat to greenhouses. Traditionally windmills are seen as machines for grinding grain and thus have a long history on farms; the current interest is a continuation of this earlier use. Although earlier classified by the Department of Energy as only 'promising but uncertain' (ETSU 1985b) there is now considerable optimism that small wind generators (i.e. up to 500kW) are now economically viable. Even before the Energy Act 1983 some researchers believed on the basis of their calculations that 'the wind turbine can be an economic alternative to many existing uses of fossil fuel in the rural community' (Halliday & Lipman 1982).

Similar optimism was shown by Stobart at about the same time; he suggested that at a price of about 80p/peak watt installed capacity wind generators on farms were attractive and could be used for a variety of purposes including fertiliser production, grain drying and greenhouse heating via heat pump and heat store (Stobart 1983). More recently

Boyle has given support to the medium sized wind turbine on the grounds that it is more economic than the larger variety calling for the creation of experimental wind farms to evaluate environmental impact and economies of scale (Boyle 1988). In 1990 with the temporary halt to the nuclear power programme, the 20% allocation to non-fossil fuels under the electricity privatisation proposals and current price of windgenerated electricity (both capital and running costs) now quoted to be very competitive with other forms, the future seems set fair for wind generation on farms.

The passing of the Energy Act in 1983 created renewed interest in wind based on the belief that electricity could be produced and either sold or used on the farm thus widening the scope for operation and overcoming the need for local storage. John Twidell's work on wind power and the Energy Act suggested that the integration of wind turbines with the electricity network is economically viable, but the system would need to be load managed and optimised if profitability is to be assured. The viability of such systems depends not only on the availability of wind and the efficiency of the equipment, but also on the local electricity tariff arrangements - an area of concern which still has to be resolved (Twidell 1984).

The same topic was considered by other researchers soon after the publication by the Area Supply Boards of their proposed tariffs under the Act. After careful study they concluded that Area Board charges significantly influence the economics of wind generation such that the most profitable situations are those which either provide only a small proportion of local demand or are rated at more than 100kW and essentially intended to supply the main electricity network. This was not particularly good news for farmers at that time, but as they concluded, farm produced wind energy may still have the edge if it is not subject to punitive local rating for wind generator installations (Clare et. al. 1983). Under the terms of the recently introduced Uniform Business Rate such local differences should not exist and small private producers should be better fitted to compete with the large companies.

In addition to tariff arrangements the work of Nitteberg and others on cost sensitivity which took place at about the same time showed the influence of other variables on the cost of wind generated electricity. Apart from the key factors of availability and capital cost the most significant influence was mean wind speed such that a fall of 30% could require a doubling of the price per unit of electricity to maintain profitablity (BWEA 1987). As windturbine output varies according to the cube of the windspeed this is not unexpected, nevertheless it does emphasise the importance of siting windgenerators in places where the wind blows strongest and the considerable uncertainty of marginal sites.

A comprehensive study looking at the farming issue in more detail is based upon five wind generator types with two wind regimes supplying power to poultry, dairy, pig and glasshouse farms. Using Electricity Council figures, calculations were made of the import and export of power on an hour by hour basis for large, medium and small poultry and glasshouse farms as well as large dairy and pig farms. The tariffs of five Area Boards were considered for the year 1984/85 using the Real

Rate of Return method to determine viability. The study suggested that about 1300 farms would be viable at a real rate of return of 5% on capital, but 'this number would increase sharply given more benevolent tariffs or a reduction in manufacturing costs.' Most of these were dairy farms which is more a refection of the absolute number of such farms compared with the others rather than their location or the energy which they consumed. No farm was seen to be viable where the average mean wind speed was 5-6m/s, but at 6-8m/s some poultry farms were viable in each of the five areas considered. Only one make of wind turbine was seen to be economically acceptable, namely that of Polenko at the 40 and 60kW size (Page 1986).

In addition to the Energy Act there has been pressure over the years to encourage government grants for wind energy rather like those available in the U.S. and some European countries. A case was made on behalf of small wind turbines suggesting that aid towards a test centre together with a co-odinated programme and set of grants and subsidies would enable wind to get over the 'commercial hump' (Lipman & Halliday 1983). Such grants are now available under the terms of the Agricultural Improvement Regulation 1985; the Regulation offers grants ranging from 15 to 50% depending on the favourability of the area and the type of installation (HMSO 1985). A National Wind Turbine Centre now exists at East Kilbride in Scotland, but without the general subsidy which was suggested.

A sample of the continuing research effort could include the South of Scotland Electricity Board's experiments with 15 and 60kW machines in conjunction with an agricultural college (Bedford 1986), windturbine economic modelling at Imperial College and Sunderland Polytechnic and the study of environmental aspects at the Open University (Grubb 1990; Clarke 1989). A number of machines are now operating on farms in a variety of applications and conditions with promises of technical success and a reasonable rate of return on capital (Far. Wk. 1986, 1988a, 1988b & Roberts 1990).

According to Page (1985) the potential for energy production with the widespread installation of wind turbines on farms is about 250GWh or twenty times current farm electrical energy take. Although not a large figure in national terms this represents a significant opportunity for additional farm income through sales to the National Grid. The case for wind energy in terms of running costs has been adequately demonstrated, but for most farmers the largest economic hurdle still remains this initial purchase and installation of the machine. Farmers could be helped in this by the emergence of small consultancies dedicated to the development of wind energy on farms.

5.6 Solar Energy.

Solar energy is the basic energy form for the growth of plants, whether in the open or enclosed in greenhouses and as such in not new in agriculture. The greenhouse is itself a solar energy device for enhancing the energy from the sun, but more recently other solar devices have been tried in UK agriculture to heat water in a milking parlour, assist in the drying of grain and other crops and to provide warmth for the rearing of livestock. The most detailed estimate of the national solar heating potential from a study of sixteen farm applications in the UK is given as 4.4 PJ/yr; 3.6 PJ of this is for glasshouse heating with only grain drying at 0.53 PJ of any real significance (ETSU 1985a).

Other areas of solar application have been tried such as the use of solar panels to heat water in a milking parlour at the Seale-Hayne College dairy in Devon. The 'herring bone' form of milking parlour catered for a 100 cow herd with a milk yield of 6000 litres per year. Monitoring took place during the summer of 1983 and the results showed that a maximum water temperature of 65 degrees was realised giving some 60% of the heat required for plant cleaning and cow hygiene. As with the use of active solar heating in domestic situations it was found that in terms of simple payback the system was not economically viable and other methods of saving energy in milking parlours such as heat recovery from bulk milk tanks (as already refered to) is to be prefered (Carpenter et. al. 1983; ETSU 1985a).

Considerable technical success has achieved in Europe using the solar energy method of drying. The principle is that air is warmed either directly in a solar panel or indirectly by drawing it through a fibrous material which has been warmed by solar energy. Examples of solar dryers have been recorded from sunny Greece and Italy to temperate Scotland and cold northern Norway. There are reports of work in Germany, Sweden and Switzerland as well as England. Such dryers can be stand alone or be fossil fuel assisted with oil or gas. Solar drying using Swedish equipment has been tried in the UK with some success;

claims for one dryer are that energy requirements were cut by between 33 and 50% giving a payback time of 3 to 4 years (Far. Wk. 1987a & 1987b).

An ADAS study used solar energy to overdry batches of barley to nearly 8% moisture content early in the season. This was then mixed with 19% dry wheat at harvest to produce a mean moisture content of 15% which was 90% achieved in three days with no evidence of fungal decay after eight months (Burrell 1982). A Swedish experiment using an indirect method of air heating showed that it is possible to dry 1000t/year for £600 with a 300m^2 solar collector (Far. Wk. 1985). A comprehensive study of solar drying in Scotland for hay and grain showed a 52.1% reduction in energy for hay and 25.7% reduction for grain. The difference can partly be accounted for by the generally warmer weather available in Scotland during the hay season conpared with the weather at harvest in the autumn (Gibb 1985).

Although there has been some success with solar drying in the UK, in general the technology has been no more successful economically than active water heating. An ongoing programme of research using a "solar barn" has been conducted by the Scottish Institute of Agricultural Engineering from which a number of papers have been produced over the years (Ferguson & Graham 1983; Ferguson 1983). The work has shown 'that a large solar air heater of simple construction can significantly contribute to energy saving for the forced air drying of farm crops.'

However the studies have also shown that solar assisted drying is generally not economic at current fuel prices particularly as the hay and grain drying seasons together only extend over a few weeks. The way forward is to reduce construction and maintenance costs; if fuel prices again rise at a faster rate than labour and other capital costs, solar grain drying could become viable if long term payback is acceptable and the energy consumed in the construction of the barn does not exceed that gained from the sun.

Another area of application for solar energy is to heat the air, water or food used to rear livestock. It has been reported that calf, poultry, pig and fish production can all be assisted economically using solar energy as a supplement to the normal methods of heating (ETSU 1985a). Experiments were successfully conducted in Holland using solar collectors to provide hot water for a variety of uses such as cleaning, food preparation and floor heating (Schepens 1983).

In addition to the use of active or passive solar collectors, solar energy can be employed in the direct conversion to electricity using solar cells. Assuming a considerable fall in the price of modules it has been predicted that solar cells could provide about 10% of Europe's electricity requirements by the year 2000 (IEE 1984) but much of this must be for the sunnier countries of southern Europe rather than the UK. No doubt due to their present relatively high cost, there appear to be no significant experiments using photovoltaic (p.v.) systems in agriculture in the UK. A more recent report predicts that p.v. systems will have to fall to between one fifth and one tenth of their present level before they become economic in the UK. In other words the present price of \$5/W to 6.5/W will have to fall to about \$0.75/W before p.v.

technology is widely adopted on farms and everywhere else (Elect. Rev. 1987). More recent estimates put this at about \$2/W and this could be achieved if mass production of p.v. cells were to become possible.

Table 1. Summary of Main Data on Fuelwood Production..

(i) Principal Wood Production Regimes..

Short rotation coppice.	3 - 8 years; 10,000 to 20,000 trees/ha.
Longer rotation single stem.	12 - 20 years; 5000 to 10,000/ha.
Conventional.	40+ years; usual spacing for mix of species.
Modified conventional.	40 - 60 years; Conventional species in higher densities.

(ii) Principal Varieties..

Eucalyptus, poplar, willow.	(Coppice)
Douglas fir, southern beech, sitka spruce, sycamore.	(Single stem)
Spruces, firs, pines, sycamore, ash, birch, beech.	(Conventional)
Spuces, pines, sycamore, ash, birch.	(Mod. convl.)

(iii) Yields.

15 - 20 tDM/ha giving energy potential of 300 - 400 GJ/ha.	(Coppice)
11 - 14 tDM/ha Giving energy potential of 220 - 280 GJ/ha.	(Single stem)

(iv) Estimated Planting Areas in the UK..

0.09 Mha giving output of 1.36 MtDM/yr. (1983 est.)	(Coppice)
0.73 Mha giving output of 3.32 MtDM/yr. (1983 est.)	(Conventional)

A potential of almost 1.0 Mha has been suggested (Dept. of Energy 1988b) but could reach 4.4 Mha total woodland under best conditions.

(v) Economic Viability and Prospects..

Good prospects for energy-forestry in general where it addresses specific local, regional or national conditions. Limited potential for agro-forestry without generous grants. Most promising UK locations are where forestry replaces livestock or cereals on poorer land or on larger farms with higher incomes and near markets. Agroforestry awaits further research to gain better understanding of interaction between components, empirical data on yields and ways or overcoming constraints before wider employment (Carruthers 1989).

(vi) References.

Apart from those specially mentioned, data drawn from references given in section 5.2.

Table 2. Summary of Main Data on Catchcrop Production.

(i) The Principal of Catch Crop Regimes.

Catch crops sown between harvest and the end of the season to make use of the window of growing opportunity and provide feedstock for biogas and fertiliser production.

(ii) Principal crops.

Stubble turnip, fodder radish, forage rape, mustard, kale, sterile brome, forage pea and quinoa.

(iii) Yields.

Yields will vary depending upon the crop, time of planting and seed rate.
Studies have given yields ranging from 13.9 tDM/ha for fodder beet sown in June to 2.5 tDM/ha for fodder radish sown in mid-September. These will enable biogas energies of 244 to 74 GJ/ha respectively to be realised.

(iv) Estimated planting areas in the UK.

This also depends upon the planting time. Adding the areas from June to the end of the season an estimated 4450 ha is potentially available or some 85% of the current total tillage area to yield about 380 PJ of biogas energy.

(v) Economic Viability and Prospects.

Catch cropping currently not viable. Land gives better economic returns when used for animal feed and gas out put from digesters lags that obtainable using animal wastes as feedstock. The technique awaits a dramatic increase in fuel prices or political support in alternative land use.

(vi) References.

Data drawn from those already refered to in section 5.3.

Table 3. Summary of Main Data on Other Crops and Wastes.

(i) Principal Processes.

Materials can be used for all form of energy processing as shown in Appendix 2 to produce heat, gases, oils and electricity.

(ii) Principal varieties.

Natural vegetation	Bracken, cordgrass and knotweed.
Vegetable wastes	Straw, potato and beet.
Amimal wastes	Dairy cattle, pig and poultry manure.
Other crops	Cereals, beet and others surplus to food requirements.

(iii)	Yields.	Energy Content.
Bracken	About 6.0 tDM/ha-yr.	150 GJ/ha.
Cordgrass	About 16.0 tDM/ha-yr.	90 GJ/ha.
Knotweed	About 10 tDM/ha-yr.	200,GJ/ha
Straw	About 2.0 tDM/ha.	14 GJ/t.
Potato	About 2.0 tDM/ha-yr.	10 GJ/t.
Beet	About 4.0 tDM/ha-yr.	15 GJ/t.
Dairy cattle	About 1.5 tDM/cow-yr.	6.0 GJ/t.
Pig	About 1.0 tDM/sow-yr.	9.8 GJ/t.
Poultry	About 12.0 tDM/1000 head/yr.	8.8 GJ/t.
Cereals (grain)	From about 5.0 to 8.0 t/ha depending upon variety.	7.6 GJ/t

(iv) Estimated planting and stocking figures in the UK.

Bracken	About 0.32 Mha currently in the UK.
Cordgrass	About 12,000 ha currently in the UK.
Knotweed	About 0.75 Mha could be planted.
Straw	About 7 Mt/yr could be used for energy.
Potato	About 350 ktDM/yr.
Beet	About 800 ktDM/yr.
Dairy cattle	About 4600 ktDM/yr.
Pig	About 1000 ktDM/yr.
Poultry	About 1500 ktDM/yr.
Cereals (grain)	Intervention stored grain; varies, but could be 5Mt/yr surplus to UK food requirements.

(v) Economic Viability and Prospects.

Natural vegetation	not viable; no immediate prospects.
Straw	viable now for farm combustion and local industrial use; up to 1.6 Mt/yr could be used by year 2000. Not yet viable for further processing.
Vegetable waste	not yet viable for its only use, as digester feedstock.
Animal waste	not yet economically viable, but can be digested now as part of a packet of measures.
Cereal grain	not viable or as yet, politically acceptable in the UK. As for catch crops, this area awaits a rise in fuel prices or political support as agricultural policy changes.

(vi) References.

Brandon O. and Price R. (1985).
Carruthers S. (1986).
Clegg J. et. al. (1985).
ETSU (1989a).
ETSU (1989b).
Hall and de Groot (1987).
Larkin S. et. al. (1981).
Martindale L. (1986).
Sims R. and Richards K. (1986).
Mitchell (1987).

In addition to those listed above, data has been drawn from references mentioned in section 5.4.

Table 4. Summary of Main Data on Windpower.

(i) Principal uses of Windpower on the Land.

Windpower can be used for pumping, providing mechanical power or as an energy source for the production of electricity for farm use of for sale.

(ii) Windgenerator Specifications.

The horizontal axis windgenerator of up to 300 kW is considered to be the best type and size for farms. This type enables land around the generator to be farmed; the size is considered to be optimum for agricultural farm use but machines up to 250 kW have been suggested.

(iii) Technical Potential for Windgenerators on Farms.

Technically windgenerators could be installed on most farms, but is best on sites where the mean annual windspeed is about 7 m/s. If 1% of farm land was set aside for windturbines about 500 GW of installed capacity would be possible (IEE 1989).

(iv) Economic Viability and Prospects.

Page (1986) suggested that on the basis of a 5% rate of return and with a windspeed greater than 6 m/s, windpower is economically viable on about 1300 farms in the UK producing about 250 GWh of electrical energy. A later study has suggested that about 20 GW of installed capacity is possible now (Swift-Hook 1988). Currently with the collapse of the nuclear power programme and the privatisation of the electrical supply industry, the future looks more promising but also uncertain. The critical questions for farms are wind speed, rating charges, contract lengths and local electricity tariffs.

(v) References.

Apart from those specially mentioned, data has been drawn from references given in section 5.5.

Table 5. Summary of Main Data on Solar Energy.

(i) Principal Uses of Solar Technologies.

Space heating, water heating, grain drying, electricity production.

(ii) Principal Techniques.

Greenhouses	Plant propagation and development.
Solar panels	Water heating, crop drying.
Heat pump cycle	Grain drying, milk cooling/water heating.
Photovoltaic cells	Electricity production.

(iii) Technical Potential for Solar Technologies.

Greenhouses	Use nationwide with energy potential of 3.72 PJ/yr covering propagation, development and root zone warming.
Solar panels	About 0.6 PJ mainly for crop drying.
Heat pump cycle	0.1 PJ mainly for dairy use.
Photovoltaic cells	Not yet known.

(iv) Economic Viability and Prospects.

Greenhouse use currently viable in all sectors.
Solar panel and heat pumping techniques are viable in particular applications depending upon the system and material circumstances.
Photovoltaic cells as yet too expensive other than for special circumstances.
Prospects will improve as energy costs rise and photovoltaic cells fall in price.

(v) References.

McCarthy (1987).
Olivier et. al. (1983).
Apart from those mentioned above, data drawn from references given in section 5.6.

Chapter 6. The Constraints and their Effect on Energy Production on the Land.

6.1 Introduction.

As with all technologies, the constraints which determine the shape of farm technology take a number of forms. Moreover these individual constraints work together to form a matrix which ultimately determine its form, pace and extent of development. Some constraints are of a form which appear whatever the nature of the technology whereas others are peculiar to one particular form. For example, a constraint general to all technologies is the human perception held by those who are in a position to make a major contribution to its future. A particular constraint on farming technology could be the quality of land and the climate to which it is subject.

It is generally assumed that socio-economic constraints are either fixed or change only very slowly. However all such constraints can be considered to be in the process of change due to the natural course of events or amenable to change as a result of deliberate human action. Whatever the case, constraints involving people are frequently seen by technologists as less easy to solve than the technical influences. Moreover, engineers and scientists find the technical route more within their competence and are happy to leave the non-technical constraints to others. In spite of this frequent reluctance to tackle socio-economic issues, it is likely that a small change here will have a greater impact upon conservation and the take up of solar devices than (say) a large breakthrough on some technical aspect. For example, a small change in the economic climate or the availability of a government grant can change the prospect for a particular technology overnight.

Even some physical and technical constraints once considered to be unchangeable should now be seen as fixed no longer. An example of this is the climate; much debate is taking place to assess the likely influence of the greenhouse effect upon the future of farming and if certain predictions come to pass, UK farming in the middle of the 21st century could be very much different from today.

Researchers who attempt to construct constraint models in order to gain a total picture and predict the likely outcome of certain changes from the present, face the twin difficulties of parameter base and relationship. A common base for many computer models is money; attempts are made to reduce all parameters to a monetary value and then on the basis of historical evidence seek to relate these values in a comprehensive set of monetary equations. Although useful these exercises are of limited value; many important variables (such as human attitude and political change) are impossible to assess in this way and their interrelationships tend to change with the parameters.

In other words it is not possible to generate general socio-economic laws as in the natural sciences because what people do under a particular situation is determined as much by their knowledge and values as the situation itself. Social science can attempt to quantify the incidence of an action in a given situation and may use it to show that what we believe will be the outcome to be false. Hence although such work may show that our common sense is not to be relied upon it is a doubtful tool for making long term predictions or as a guide to the kind of actions which are necessary to ensure a particular outcome. It also raises questions of whose values are behind the models which suggest a certain course of action, however well intended.

A number of recent computer based studies have attempted to model the interaction of a limited number of constraints to determine their relative importance and effect (Page et. al. 1986; Carruthers 1985; Jones 1984). These center on economic influences such as grants, interest rates and the cost of energy derived from conventional fuel sources. In general the conclusions reached are that at the time of the study and under a specific set of circumstances, certain technologies (for example short rotation forestry) are viable but others will only become so if generous grants are made available or there is a dramatic increase in the price of conventional fuels.

Other studies have listed the constraints and offer solutions as to how these may be overcome. As with the computer based studies these approaches tend to be economic in nature with occasional references to the need for education and change of attitude (Sourie & Killen 1986; Strub & Steemers 1980; Carruthers & Jones 1983). Constraints can be listed under a number of headings as follows.

6.2 Technical Constraints.

The most obvious technical constraints are the feasibility, reliability and efficiency of present and future technologies. Application can also be limited by such things as the robustness and efficiency of the equipment, the ease with which it can be installed and the availability of servicing and spare parts. Secondary issues include the extent to which equipment increases or reduces pollution or generates a useful by-product. Farmers may also be concerned about the rate at which new technologies become obsolete.

In the context of this study, technical constraints in farming can be described as the need to maximise output per unit of material and energy input. Farmers are thus interested in raising or maintaining crop yield with the same or reduced energy input in the form of chemicals or machinery. This suggests research in plant development, fertiliser regimes and harvesting techniques; there is also interest in more efficient plant processing techniques such as briquetting and digestion.

As was suggested in the Introduction, technical constraints attract much interest as they are perceived, particularly by the engineers and technologists, to be more easily tackled than those with socio-economic content. Technical issues are seen to be more reliable and the work readily repeatable without reference to non-physical variables. Hence the considerable amount of work that is being pursued in biomass studies even though more effort elsewhere could bring greater reward in terms of energy conservation take up and the use of devices to generate energy.

6.3 Energetic Issues.

Energetic issues may be seen as another form of technical contraint but in the context of farming it is a matter of judgement as to whether it is an issue at all. As was observed in Chapter 1, apart form the glasshouse sector, energy is not seen by many farmers as an issue of great significance in any case and energy costs, either direct of indirect, can be easily passed on to the customer. Greater consciousness of energy as an issue may not come until farmers are forced by circumstances to produce energy as they now produce food. As yet energy issues as such cannot be seen as a major constraint on the land.

Where there is an interest in energy production on a farm the constraint could be one of matching supply to demand or ensuring that some form of buffer energy storage is available to bridge the gap. Thus although an interest in alternative energy may exist on a particular farm it may not go ahead because it is not possible to match the energy output of the device to the mix of energy input requirements. It may be necessary to install two or more devices working in concert to ensure that needs are met throughout the year particularly during the winter months when demand is likely to be greatest. For example, in isolated communities without a mains supply of electricity, a diesel/wind generator system could operate.

At the broader level farmers are unlikely to get much assistance from the major energy utilities and the continuing development of energy management techniques could reduce the demand for energy generally on the farm and hence for alternative devices in particular.

6.4 Economic Constraints.

This is the most commonly quoted constraint and involves a broad range of issues centered around financial, marketing and policy matters. The boundary between a viable and lossmaking enterprise is very thin and one cannot assume that once this has been crossed into viability that things will remain much the same indefinitely. In the past farmers have been able to assume that they could dispose of all the food they produced and at a price set not by the market but by government which ensured a profit. Although overproduction and set-aside policies now challenge this belief farmers will not be able to abandon their habits and assumptions overnight. The wide range of economic concerns which farmers are likely to express will reflect these old patterns of thought and action.

For example, given that a capital cost is usually involved in any new enterprise, farmers will be interested in the time taken to achieve payback and hence the availability of grants, subsidies and tax benefits. Where land normally used for food production is involved (such as when energy crops are considered) the issue is one of opportunity cost. Farmers will naturally be concerned about the cost of conventional fuels compared with those of energy produced on the farm. In the case of electricity they will want to know whether they are able to compete on broadly similar terms with the major electricity utlilities and the return from the sale of electricity to the National Grid under the terms of the Energy Act 1983.

On the broader issues of the economy in general, there will be concern about the level of interest rates, the availability of loans and the size and proximity of the market for biofuels. Looking to the future there will be uncertainty about food and energy prices, discount rates, the level of inflation and the present and future state of the economy. The absence of any coherent policy for energy and the land coupled with the consequences of a change of government will also tend to delay decision making.

6.5 Farming Attitudes.

Although like any other professional body the farming community will have certain broad attitudes in common, there will be still exist a wide spectrum of belief ranging from those who, apart from the matter of cost, will lack any strong interest and enthusiasm in the conservation and generation of energy, to those who will readily and enthusiastically take up the challenge. A study to investigate the attitude of Irish farmers to agroforestry was revealing in this regard; it was found that the willingness to adopt forestry was associated with larger farms, better education of the farmer, the extent of off-farm income and younger farmers. This points in the direction of the more flexible, energetic and advantaged farmers who have larger holdings and wider financial interests; practical experience of tree planting did not appear to be a significant factor (Hummel 1988). As far as forestry is concerned the outlook of farmers could be considerably influenced by their interests and experience; for example, dairy farmers who are used to a regular income from the sale of milk may be less enthusiastic for forestry than cereal farmers for whom annual returns for crops is an accepted thing.

Thus like other businessmen, farmers are willing to adopt new practices if they find them attractive and it is in their financial interest to do so. Nevertheless there are other issues which could influence farmers concerning their particular situation when alternative energy devices are under consideration. Firstly they will be interested to know how these alternative methods will integrate with their current crops and practices. They will want to see effective demonstrations of the equipment and be persuaded that a satisfactory organisation exists from which they can gain the necessary support. Others will wish to assess the extent of the risk associated with these devices or consider how they ~~they~~ match with their particular life style. There will be farmers who are indifferent to energy issues or are ignorant of their potential. Finally there will be a group who are simply reluctant to try new methods and reject alternative energy as they would anything else.

Farm attitudes therefore form a major influence on the take up of energy issues particularly where a technology is on the threshold of financial viability. As earlier examples have shown, farmers can be found who are pursuing energy conservation and generation interests in all sectors even when the financial return is somewhat doubtful, but the majority will require much greater encouragement before they persuaded to take the step.

6.6 Labour and Land Issues.

As the data in Chapter 1 showed, the number of those regularly employed on the land has been falling continually since the end of the Second World War and now stands at about 200,000 people or 1% of the total UK workforce. This has been made possible and necessary by the introduction of capital equipment and the rise in the salaries and wages of employees. Under the present circumstances this trend is likely to continue and could be accelerated by the advent of set-aside policies; any move into energy production on the land could require a reassessment of labour requirements particularly if this labour has to be of a special quality. For example, as was observed in chapter 5, anaerobic digestion plant operates most successfully with specialist and dedicated staff.

Hence farmers will be interested to know whether the employment of alternative devices will require extra skilled labour or if training is required to bring their present staff up to the level required. It is one of the claims of the alternative technology movement that AT has the potential to create much needed jobs, but farmers are unlikely to be happy if extra labour is required on the farm if it is not matched with energy savings or the earning of money which will at least compensate for the cost of that labour. The farmer or landowner, unless he is knowledgeable about the new technologies, will have the problem of efficiently managing the the new labour and will thus have to assess the matter from a personal as well as labour point of view.

Farmers may also be reluctant to undertake energy activities because of the size and location of their farm. A farm of 50 ha. or less may be considered by the owner to be too small for the production of biomass energy, particularly if he wishes to integrate this with conventional food production activities. A small farm located in a windy part of the country may be ideal for electricity generation, but the problem then becomes one of the extent to which the enterprise is to set the relative levels of food and energy production.

Labour and land issues are likely to be major considerations for farmers who consider the options of energy generation. The labour aspect raises questions of knowledge, skills and the availabilty of reliable information, always important when new technologies and techniques are at issue.

6.7 Public Attitudes.

The attitude of the general public towards alternative technology (AT) devices and their use on the land could influence farmers. The exaggerated claims which have been made on behalf of some devices will not have escaped notice and the assumption that AT is associated with lower living standards is still sufficiently common for farmers to be influenced in the same manner as others. With agriculture currently blamed for much of the loss in beauty and amenity in rural areas farmers will not wish to risk further damage to their public image.

For example people living in the vicinity of farms may object to changes in the visual landscape or loss of local amenity due to the extra traffic, noise or pollution produced. Monoculture wood production could attract such criticism for short rotation forestry wil not produce places where pleasant country walks can be pursued; on the contrary it could mean the loss of attractive views and public foot paths. Noise and the interference of television reception could result from large scale windgeneration and local people may see windturbines as 'in their back yard' and therefore unacceptable.

6.8 <u>National and EEC Issues.</u>

At the national level, government policy on such matters as energy, the land or the environment will influence farmers. For example, farmers could be influenced by the tendency of government and large institutions to favour large centralised energy systems in preference to small AT or the "official" view that alternative energy production will never be able to contribute more than a small percentage to national energy needs. Although some financial support is available for new capital equipment which could be employed for energy generation, the farming industry is likely to recognise the absence of any comprehensive energy policy and limited enthusiasm for AT which seems to exist in government circles. As far as wind in concerned, farmers will wish to wait until the picture on energy privatisation becomes clearer, but the new electricity utilities will still remain very large organisations and thus able to determine the conditions under which small operators will compete.

When considering the role of the EEC, it may be necessary at this level to co-ordinate the production of food, energy and wood. As 1992 approaches and the age of the European market begins, any move into large scale agroforestry for example will have to be considered in the European context. Judging by the level of interest shown by the EEC towards alternative energies generally, British farming has less to fear from Europe than from its own government in this regard; the European Common Agricultural Policy could positively influence the production of energy on the land through changes in the value of the Green Pound or as part of the current rethink of land usage throughout the EEC.

6.9 Legal and Institutional Constraints.

Under this heading issues include such things as planning controls, land ownership constraints, water catchment and restrictions on land used by the armed forces. For example, coniferous woodland may not be allowed in or near areas of outstanding beauty and wind generators may be resticted near military airfields. The users of tenanted land will not have the same degree of freedom in how they use it as freehold farmers and some land may be legally limited on it use. Farming is generally free of rating and planning constraints, but the new Uniform Business Rating System together with large scale introduction of energy technologies on the land could lead to changes in this regard.

Legal constraints are not major impediments to the development of energy production on the land but the resolution of such impediments where they exist could take time to be resolved. The institutional constraints are more difficult; where there is a case of an imbalance of power and influence between the promoters and detractors of a scheme to use land for other purposes (such as the government on the one hand and an individual farmer on the other) the matter may defy resolution until there is a change of economic circumstances, public opinion or government to make resolution possible.

6.10 Environmental Constraints.

Some reference has already been made to certain constraints in this area which in the light of current concerns such as nitrate pollution and the loss of wildlife habitat are likely to grow in the future and make them one of the major influences on future land use. An example of a current enviromental concern which could affect energy production is that regarding woodland where it is claimed that present methods of tree production based upon close packed non-native varieties are prejudicial to access, wildlife and the visual appearance of the land (Pye-Smith 1984).

In the future concern could be expressed that the production of methane on the land, with the inevitable loss to the environment, would add to that which is already escaping through natural means or from the North Sea gas industry, of what is a well recognised greenhouse gas contributing to global warming. Its near chemical neighbour, methanol, if produced on the land could also be the target of environmental concern for it has been claimed that long term exposure to the substance can cause blindness, brain damage and ultimately death (Homewood 1990). Any process which will to add to the release of nitrous oxide (another greenhouse gas) into the environment from gentically engineered nitrogen fixing plants (already refered to) is likely to be resisted if the amount is significant.

Even electricity production could have its environmental critics. Apart from noise and visual appearance issues already mentioned there is a growing concern, particularly in the United States, at the possible biological damage caused by low frequency non-ionising electro-magnetic fields. However, this can be discounted for the relatively low voltage windgenerators compared with the possible impact of (say) the 400KV Supergrid (Best 1990).

7.1 The Advantages of Energy Production on the Land.

As a counter to the above constraints, there exist certain advantages to the land and farming which are worthy of consideration. For example the positive side of the production of biogas in a methane digester can help to reduce the odour emitted from animal waste and produce valuable fertiliser. Moreover by putting waste in a digester rather than leaving it to decay naturally, methane is contained; if the gas is then ultimately burned this has the effect of turning the it into CO_2, a much less potent greenhouse gas.

The production of energy crops such as wood could aid weed control. At the wider level, growing wood may be preferable to leaving land out of production at a time of food surpluses. It is possible that growing energy crops rather than food would require less N fertiliser or less effort on behalf of the farmer. More trees if planted and managed with the environment in mind may encourage the return of wild life to places where they are absent or prevent the erosion of valuable top soil.

If energy production is such as to make it possible for more labour to be employed, this could help to reduce the drift of labour from the land and assist in the development of rural communities. The taxpayer may be more willing to support a continuing subsidy on the land if the money is being used to produce a worthwhile commodity rather than simply prevent land from drifting into impenetrable wilderness. At the national level and against a background of diminishing oil reserves, energy production could significantly reduce the UK dependence upon imported fuels and thus assist in controlling the balance of payments.

Chapter 7. Final Conclusions and Recommendations.

7.1 Introduction

Any conclusions on the use and generation of energy on UK farms between now and the turn of the century must be set in the context of the possible shape and place of agriculture during that period. These will largely be determined by forces external to the industry, some of which have been generated as a result of what has happened in agriculture during the last 40 to 50 years. The chapter identifies five forces which will principally determine this shape and place and these will be discussed in the sections which follow. The chapter will conclude with a number of recommendations.

7.2 Trends in UK Farming During the Next Ten Years.

Agriculture's share of the national economy, currently about 1.8%, is forcast to continue its decline to about 1½% and its work force fall a further 10,000 or so. The decline in farming income in real terms of about 40% from its level in the early 1970's is also likely to continue although the fall in the real income per farm will be less due to the 25% increase in average farm size over the same period. In spite of this general increase in farm size it is suggested that large intensive holdings will remain a relatively small proportion of the total with 80-85% of the output being produced by the 70-80,000 farms in the centre. The current self sufficiency level (that is the proportion of food produced on UK farms compared with the total of food consumed) of 57%

could continue to fall if there is a turn away from intensive farming towards extensive or organic systems (Jackson G. 1990; Nix 1989).

Farm debt increased subtantantially during the 1980's and now stands at about £6000M; this is a large, but considering the size of the industry, not an insupportable sum. The farming industry also runs at a financial loss; this is likely to continue during the present decade with business only maintained by government and EC funds. Whatever happens to farm subsidies in the future, economic uncertainty will ensure the continuation of the drift of capital out of food production into other forms of investment, but some of this new investment into alternative enterprises could be to the advantage of energy production technologies which are seen as economically attractive.

Although from the above farming appears to be in decline it should not be assumed that this is associated with less energy being consumed on the land. As earlier data shows, the decline in labour is part of the process of replacing man by machine and as yet there is no evidence that other heavy energy takers such as agrochemicals are falling in popularity. A safer assumption would be that this aspect on its own will not lead to a significant change in the agricultural energy take.

7.3 <u>The Overproduction of Food and its Consequences.</u>

Although in terms of product value, labour and available land farming is a declining industry, crop yields and tonnage of output, particularly in cereals, has risen to such an extent that there is now serious overproduction. This situation has been achieved through normal technical advances and stimulated by the British government and the European Common Agricultural Policy. There is no reason to suppose that the limits of production per hectare have been reached and now that the technical capability is there, barring any restrictions through legislation or government directive, it will continue to be used.

This success story has proved to be to the industry's disadvantage, for with new controls on production it faces the prospect of up to 1.5 million hectares or about 10% of the total arable and grassland being categorised as excess to need. It has been suggested that by the year 2000 Britain may have to reduce its cereal acreage alone by 3 million hectares, and by 2010 over 5 million hectares may be surplus to food requirements (Milne 1987). Farmers are being encouraged with government grants to take up to 20% of their land out of production; the land must be kept in good condition or used for non-agricultural purposes (MAFF 1988a). It has recently been estimated that 1M ha. of short rotation forestry could provide 6% of the UK national electricity requirement (Carter 1990).

This 'set-aside' policy has caused land prices to fall and stimulated a search for new enterprises; all manner of activities have been mentioned from alternative crop and animal systems to recreation and tourism (Carruthers 1986a). One exception to the set-aside rules is the planting of trees hence the considerable interest currently being shown in forestry, an interest which could be further stimulated if the price of land falls below about £2400 per hectare (MAFF 1986).

Set-aside could have considerable influence on energy use. The empty hectares can be limed but not fertilised, and the fall in machine activity with respect to them will necessarily reduce fuel consumption. However it seems unlikely that farmers (or the country) will be content to allow up to 3 million hectares lie idle with all this means in wasted resources and further loss of labour on the land. It has also been suggested that farmers may be tempted to cultivate even more intensively the land which has not been set aside to hold current production levels, maintain their incomes at the present level and (as a consequence) hold or even increase the amount of energy used.

As yet with farmers under no obligation to set land aside the policy has hardly started to bite and in any case the whole thing could take a number of years to be fully implemented. It is therefore not possible to speculate with any accuracy the energy implications of set-aside; the matter must await the outcome of changes in the Common Agricultural Policy and the responses of the farming community to these changes.

7.4 Climatic Change.

It is now widely recognised that the man-made changes taking place in the upper atmosphere have considerable implications for the future of farming in Britain as well for the rest of the world. Looking particularly at agriculture and using a climatic model, recent researchers have predicted a rise in temperature of 4.5°C by the year 2030 suggesting that we need to begin planning now to be ready for the event (Gribbin 1990). The release of certain gases principally carbon dioxide (CO_2), nitrous oxides (NO_x), methane (CH_4) and chlorofluorocarbons (CFC's) are being blamed either for the 'greenhouse effect' or the 'holes' in the ozone layer. Although most of this gaseous release is the result of non-agricultural activity, a significant part of it is directly due to farming practices world wide.

For example, fieldwork activity causes nitrogen to be released from the soil and much of the nitrogen from fertiliser application end up in the atmosphere. The considerable increase in cattle production world wide contributes to the release of CH_4 from natural sources, and paddyfield activity in the Third World adds further to the total. The destruction of tropical forests in Brazil and other countries is contributing to the release of CO_2 in two ways; firstly it is reducing the volume of biomass capable of taking up and converting the gas into living matter and secondly by adding to it as the waste wood is destroyed.

The negative side of all this for UK agriculture is that possibly wetter winters and drier summers will force changes in crop varieties and regimes. Low lying agricultural land, principally in East Anglia and around certain estuaries, may be lost as sea levels rises in consequence of melting polar ice caps. In the event of an ozone hole appearing over Britain, plants and farmers will be subject to increasing levels of damaging ultra-violet light. Increasing temperatures will speed up the growth of plants and lead to lower yields; this could be coupled with more vigourous growth of weeds and increased plant loss due to pests and diseases.

There could also be some benefits. The CO_2 enriched atmosphere could counter the negative effect of faster growth leading ultimately to greater yields by as much as 30%. Crops and trees could be grown at a higher altitudes and cereal production, now largely limited to the warmer and drier South, could be extended to parts of Scotland where it is currently not possible. Longer growing seasons would encourage earlier main crop harvests and farmers would be able to plant Mediterranean varieties as a second crop. The increased production of grass in the South could reduce the area of land required for grazing as well as depress the N fertiliser requirement to the benefit of the land and the farmer's pocket.

Less N fertiliser would reduce the energy requirement of farming as would the heating requirement for glasshouses, animal enclosures and farm buildings generally. Higher crop yields would make fuel wood production more profitable and energy activities currently considered to be marginal or not viable such as anaerobic digestion and catch cropping could become profitable. Of course, burning wood and producing methane could add to the gases which have caused this condition to be realised, but in defence of wood it can be said that the CO_2 released would do no more than return to the atmosphere that from which the wood was produced in the first place. The prospects for photovoltaic and solar energy devices would certainly improve but a more even temperature might cut wind speeds thus reducing the prospects for windgeneration (Unsworth 1982; Hand 1989; Jackson M. 1990; McElroy 1988; Melvin 1988 and Pearce 1989).

7.5 Environmental Issues.

Environmental issues have already received some attention but in view of their likely impact on the future of farming are worthy of further discussion here. The criticisms are well known; that straw burning is dangerous, polluting and a waste of a valuable by-product; that nitrogen run-off is polluting streams and water courses as well as creating a health hazard as it passes into drinking water; that intensive farming of crops and livestock increases the chance of disease, creates undesirable odours and undermines food quality; that the use of agrochemicals adds poisons to the natural environment, threatens wildlife and reduces the long term fertility of the soil.

Such criticisms have already had their effect. Straw burning is now actively discouraged, farmers are advised to use no more chemicals than are absolutely necessary and many farmers are now turning to organic or less extensive methods. The National Farmers' Union has spoken favourably in terms of low input/low output farming but partly (it should be said) because it is realised that this can be as profitable for some farmers as the more intensive methods. This process is likely to continue and in consequence lead to a reduction in energy usage on the land. Farmers may thus take measures leading to energy being conserved even though the intention will be to avoid legislation and criticism or because they discover that it is in their financial interests to do so.

The set-aside scheme is not without dangers for the environmental future of the land. Although farmers have been offered payment to maintain set-aside land they are unlikely to give it as much attention as land growing crops and the lack of fertiliser on the land from both the bag and animals could lead to a deterioration of soil quality. On upland areas, reduced stocking and less fertiliser could result in the growth of poorer grasses and the spread of heather and bracken. More intensive cultivation of land not set aside (already refered to) could add to the environmental problems for which intensification is well known. Reversion to natural habitats for plants and animals can take a long time and would have to be carefully managed; a full return to a stable natural environment could take as long as 100 years (Milne 1987; MacKensie 1988).

7.6 Trends in Fuel Prices.

Under present conditions an upward trend in the price of fuel would be the most significant means of furthering the generation of energy on the land. Studies have shown how sensitive farm generation is to energy prices; for example, after the break-even price was passed, the rate of increase in the production of coppiced wood was shown to be 0.35 Mdt/£ or a doubling of the break even price could enable the production to increase by a factor of six (Price & Mitchell 1985c). It is therefore worth considering the factors which could cause movement of energy prices between now and the end of the century and check for possible effects on farm energy production.

Although there is considerable change taking place in the UK energy scene such as the passing of the peak in North Sea oil production, the privatisation of the energy utilities and the shelving of the nuclear power programme, all of which will have an impact upon the domestic energy scene, fossil fuel prices are ultimately determined by the international market. The current period of rapid change in Eastern Europe and the emergence of the Single European Market in 1992 are both likely to generate new demands for energy, but on the other hand world wide economic uncertainty could affect the prospects for trade and thus tend to depress energy prices.

Thus the statement that

> 'at present there is a broad consensus that world crude oil production capacity will comfortably exceed world oil demand over the next ten years' (Chesshire 1989)

if it still holds good suggests that there will be no significant increase in this key fossil fuel between now and the end of the century. This belief can be reinforced by the new political climate in Europe which may enable the vast coal, oil and gas reserves of Russia to be made available to the Western World.

The effect of world wide concern for the environment must not be overlooked in relation to energy prices. This concern is likely to sustain the search for cleaner and more efficient forms of generation, transmission and utilisation of energy, assisting in the maintenance of supply over demand and thus play its part in holding down further prices increases. Efforts to maintain of raise energy prices in order to keep consumption down (such as by the introduction of a carbon tax) or as a consequence of government action (such as the privatisation of the electricity industry) will have to operate against international market forces for energy which (in the absence of a world wide agreement on energy prices) will ultimately have the last say.

Farming cannot therefore look forward to any great increase in fossil fuel prices over the next ten years in the hope that this will enable renewable energy generation to 'take off'. Prices will tend to rise with inflation, but otherwise it would be safer to assume that barring unforseen major international disturbances, the absolute price of energy and its cost as a proportion of outgoings will remain much the same. Factors other than price are therefore likely to determine the prospects for the generation of energy on the land.

7.7 Farming and Government Attitudes.

Farm attitudes will continue to be a major determinant of the future of energy matters on the land. A family based, traditional and long established industry like farming is inevitably careful and slow to adopt new methods. An example of this is in respect of tree planting; in spite of the considerable publicity which has been given to woodland development on the land, farming opinion is cautious. The availability of grants through the Farm Woodland and other schemes is criticised as falling short of that which is necessary to make wood production a firm alternative to conventional crops and farmers have been advised to wait for better times (Haines 1987; Beaton 1988; Phipps 1983).

As noted earlier in this study, the best hope for energy initiatives on the land lies with the richer, younger and more adventurous farmers. This new generation, not brought up to expect the high input/output economy of their fathers, could find energy production attractive or have the drive and enthusiasm to experiment (MAFF 1986). It is this group that must be encouraged and informed rather than the farming community as a whole; effort focussed on this section would be more cost-effective and lead in the end to better results. One aspect of this focus could be better education on energy matters in farm schools; most agricultural studies lack firm grounding in this respect.

The attitude of the British government is also of vital importance. The present government's reliance upon market forces and its concern to hold down public expenditure puts energy conservation and alternative methods of generation at a disadvantage compared with current practices and methods. Under such circumstances there is little public money to 'prime the pump' and enable small energy producers to get started; moreover the large energy utilities and companies with their power over prices are able to limit competition. Fossil fuel generation is more highly favoured because it is seen as more reliable, controllable and politically glamorous whereas the alternatives are viewed as 'soft', decentralised and the concern of the those more likely to be hostile to the Conservative Party.

On the face of it the government gives some support, albeit limited, to renewable energy technologies. For example, the Electricity Act 1989 requires area boards to purchase some 20% of their supply from non-fossil fuel sources and forcasts that in addition and by 1992 50 MW of electricity will come from renewables rising to 600 MW by the turn of the century. This represents less than 1% of the current fossil and nuclear fuel capacity hence it will take many years before this 20% requirement can be fulfilled other than by further nuclear power plants. Since the mid-1970's the government has also sponsors research in the renewable energy technologies and has indicated its willingness to continue until the end of the century when industry is expected to take over.

However, the present government is unwilling to offer financial incentives in the form of grants and tax concessions to stimulate deployment on the grounds that they can be counterproductive if the technology lacks full development. This overlooks the fact that other energy technologies such as nuclear power, which is favoured for political reasons, continues to be largely underwritten by government even though the development is far from complete and where it is now recognised that other energy technologies fare better in the market place (Dept. of Energy 1988a). It has been argued that some of the subsidy which presently goes to farmers for cereal and other crops which are now in excess could be diverted to the production of biomass energy on the land, but similarly there are no indications that such a policy would find favour at Westminster (Hall & de Groot 1987).

Some money is available from the British government which could assist farmers who wish to save or generate energy but as yet little of this is taken up due to the other constraints which lie in the way (HMSO 1985). Depending upon the area and type of installation grants from 15 to 50% of the cost are obtainable from the government for:-

(i) the handling, storage and treatment of agricultural effluents and wastes,

(ii) wind and water powered pumps and generators,

(iii) solar and other forms of permanent and durable energy saving agricultural equipment,

(iv) permanent thermal insulation and sealing of glasshouses,

(v) the provision, installation and replacement of glasshouse heating systems.

The government's renewable energy research programme is conducted by the Energy Technology Support Unit (ETSU) which has published many reports and papers or the renewable energy technologies, including farming. Although it no doubt has an enthusiastic staff, ETSU is administratively part of the government's nuclear energy research establishment at Harwell and thus not free to pursue research or publish papers which may be at odds with the nuclear power programme. Suspicions are further raised by reports that the Department of Energy with the co-operation of ETSU deliberately overpriced the cost of wavepower electricity because it posed a threat to nuclear electricity, a move which ultimately led to the abandonment of the government sponsored wavepower research programme. It has now been admitted that a 'simple error' was made in the calculations of wavepower electricity which caused it to appear more expensive than should be the case; the research in this field is to be reinstated.

The present government is frequently criticised for not having any long term policy for energy, relying on a pragmatic market centred approach which lays down broad guidelines but lacks firm commitments for the future. This contrasts strongly with some other countries such as Denmark, Holland and Sweden where greater support for CHP and renewable energy has enabled district heating, biomass and windpower schemes to take the lead in Europe. Much support also comes from the EC, which also appears to be more supportive as it provides funds for research and alternative energy projects throughout the Community.

The Labour and other British political parties now in opposition have spoken with greater enthusiasm about renewables, and their generally more relaxed and generous attitude towards government expenditure suggests that in the event of their coming to power more money would be made available. Their intentions have yet to be translated into hard promises and any figures in this respect are unlikely to be revealed until near the next general election so it is not possible to be any more than hopeful at this stage.

Compared with the 'hard' sciences of physics and materials (or for that matter, the design of windgenerators) the science of attitude change is young, inexact and lacking a firm body of accumulated knowledge. Moreover from the days of the European Enlightenment in the 18th century

Western culture has drawn a careful boundary between the 'spiritual', and the material, between emotion and imagination on the one hand and that of observation and reason on the other. The principle separating the two has been the communicability of experience: something is real only if it can be perceived, described and measured in the same terms one with another otherwise (so the story goes) it is not worthy of serious consideration.

This communicabilty of experience is the basis of scientific and technological advance because it makes possible the transmission and accumulation of certain kinds of knowledge. On the other hand emotions, attitudes and values do not make such simple cognitive building blocks; this has led to the position where technical advance is way in front of man's ability to make individual choices and devise social changes which are able to support that advance. All that can be done under these circumstances in a civilised society is move those levers (such as education and propaganda) which are known to cause attitude change, note the effect and modify the policy if they do not work (Landes 1968).

7.8 Main Findings of the Study.

(i) The quantities of energy used in the various sectors of farming activity as calculated by Leach, Spedding, White and others are corroborated by later on-farm studies, although some of the data from these studies may not be original.

(ii) Although some change in these data can be expected over time it appears that although they are now some 10 or more years old they fairly represent the breakdown of energy use today.

(iii) There is considerable scope for energy conservation on the land. Although some of the claims made for certain initiatives may be on the high side, it appears that savings of up to 50% are possible on some areas. Although some farmers are making efforts to conserve energy in their operations there is a long way to go before the full potential is realised.

(iv) As a means of producing renewable energy, fuelwood production, windpower and heat recovery techniques in dairies and animal houses are economically viable now. Anaerobic digestion of animal wastes can break even economically where large volumes of wastes are available and where side benefits such as odour control and fertiliser production are desirable.

(v) All the usual constraints impeding the conservation and generation of energy exist on the land. In addition farmers will have to accomodate to the wider and far reaching constraints of set-aside and global warming when approaching energy initiatives in the future.

7.9 Recommendations.

From what has been said so far it would seem that there is little hope of immediate or great change in the energy situation on the land. Little hope can be drawn from evolutionary trends, fuel prices and government attitudes and although set-aside, climatic changes and environmental pressures hold out some promise this is either uncertain or some way in the future. Various forcasts of energy use on the land over the last ten years or so have given support to this view. The feeling has been that things would remain much the same with no upturn in the fortunes of renewable energy technologies until we move into the next century. For example Doerling (1977) writing with regard to the American scene saw the pattern of energy use on the land at the end of the century to be much the same as the present with a quickening of change after that as the supply oil and gas became more critical. A somewhat later and more comprehensive look at the UK scene by Wilson and Brigstoke (1980) concluded that any change from the present situation is dependant upon the fruits of further research and development coupled with incentives to farmers from government investment.

An early 1980's overall look at the prospects for agriculture in the 21st century from the American point of view again came to the conclusion that energy usage on the land would not show significate change from the present day (Rosenblum et. al. 1983). Although they saw opportunities for substantial reduction in energy usage as well as generation of new energy through biomass techniques, they believed any direct improvements will be modest unless institutional pressures were introduced at the same time to encourage the change. Coming up to date, the UK farming trends refered to in this study do not suggest that great changes in energy use, conservation or production are likely to take place between now and the end of the century.

On the renewable energy front the Department of Energy in its forecast up to the year 2025 does not commit itself to any specific figures for wind, forestry and other technologies which can be used on the land. Rather it is content with a range of possibility for each starting from zero or near zero under the worst conditions. It therefore assumes that it is possible to reach 2025 without any significant renewable energy contribution at all (Dept. of Energy 1988a). Finally energy conservation, although still spoken of by the government as a desirable aim for all sectors of the economy, lacks the financial and ministerial support of earlier times.

This is not a happy situation. The environmental case for conservation and renewable energy generation has been extensively put and is sufficiently accepted for there to be no need to repeat it here. One is therefore led to the conclusion that specific political, financial and research effort must take place to ensure that real savings and a significant renewable energy generating sector is achieved as quickly as possible. The recommendations which follow have been set out with this end in mind.

(i) <u>An Energy Policy.</u>

Although market forces have a part to play, they will not ensure that an environmentally acceptable, adequate and appropriate mix of energy technologies will be available when required. Thus a national energy policy is necessary, preferably as part of a global international strategy. Although there are plenty of forecasts of energy supply and demand up to the year 2025, there is a lack of a firm strategy of how these forcasts might be achieved. Any strategy should include a section concerned with energy use and generation on the land.

Policy discussions must involve questions of energy pricing and taxation. With world energy prices currently less in real terms than they were in 1973 before the first 'oil crisis' there is little incentive to conserve even though it is recognised that the future for fossil fuels is limited and that for environmental reasons their use must be restricted. It is this situation which has led to suggestions that fossil fuel consumption should be controlled by means of an energy or carbon tax. There is general agreement in Europe that carbon dioxide emissions should be reduced by 20% by the year 2005 and Britain could well look to taxation policies in other European countries for examples of both implementation and the likely level of success which could be achieved (Jorgensen 1990; Helm 1991).

This is not the place for a full discussion of such issues, but on the face of it if a case can be made that a poll tax will alert local people to the expenditure plans of local authorities then a carbon tax, in spite of its faults, will do the same thing for the energy content of products and services. As an example of this a recent OECD paper has suggested that a 20% tax on coal, oil and gas would halve the projected increase in carbon dioxide emissions from the industrial West over the next thirteen years (OECD 1990). Whatever the outcome of such a tax, some attention must be given to the economics of energy with reference to the social, environmental and. political consequences of simply leaving it to international pressure and market forces.

(ii) Farm Subsidies.

Farming is only maintained in the UK with the assistance of considerable subsidies for the government and the EEC. Precise figures are not readily available, but on the trends from previous years and taking inflation into account, the UK expenditure on price support must now be about £4000M or an average of £20,000 for every farm (Body 1984). The government and the EC aim in course of time to reduce this vast sum, but there is no hint as yet that it is either possible or even desirable to ultimately phase them out completely. The fact that it still remains largely unchanged after a number of efforts, demonstrates the difficulties of the exercise.

No attempt will be made here to discuss the nature of the subsidy problem, but accepting that some reduction must be secured in the long term it is recommended that for reasons given earlier a proportion of that which is currently spent to produce, store and dispose of surplus production should be diverted the conservation or production of energy on the land. This should aim in particular at those activities which are currently regarded as marginally viable such as anaerobic digestion and agroforestry. As an example, if the 5000 or so pig breeding enterprises which are large enough to justify a digester were granted £10,000 to assist with setting up costs, the total would be £50M - quite a small sum.

Grants for woodland are necessary because of the long lead time between planting and harvest. Farm Woodland Grants are already available for forestry ranging from £240/ha to £1575/ha depending upon the holding and type of tree, but this is insufficient to produce a return to the farmer comparable to conventional activity (Gready 1988). Compared with the present sum, the amount required to raise farm income from woodland activity to the level currently enjoyed from conventional agriculture would not be very great; for example, if the Grant was raised by (say) 25%, £250M would pay for the planting of 1 million hectares of woodland.

(iii) Windpower.

Reference has been made to the non-technical barriers which may put farmers at a disadvantage in the generation of electricity compared with the companies which will emerge on electricity privatisation. Uncertainty about rates, planning controls and the price that electricity boards are likely to offer, all stand in the way of windgeneration on farms. The companies, by virtue of their size, will still be able to set the price of electricity bought from farmers and others, but farmers should not have to suffer these additional disadvantages.

The situation can be corrected by making the necessary legal, institutional and rating adjustments; cost will not be a great factor and these actions may be sufficient to enable doubting farmers to make the move.

(iv) A Renewable Energy Agency.

Many have argued for an independent self-governing body to fund, support and generally promote renewable energy technologies. The Energy Technology Support Unit (ETSU) is constrained on two counts; firstly it is funded and controlled by the Department of Energy and secondly it within the orbit of the government's nuclear research establishment. It therefore can only do that which meets with government approval and is thus unable in its own right to fund and promote renewable energy.

Although there are companies like the Wind Energy Group and The Association for the Conservation of Energy funded by the insulation industry to promote their own interests, there is no private body with an overall perspective on renewables. Such an Agency would be free, like the Atomic Energy Authority, to generally promote all forms of renewables and seek funding from industry, commerce and by selling its services. Although it may not have any direct link with agriculture its efforts could assist such activities on the land as elsewhere.

(v) <u>Farming Education</u>.

Farming education will have to change in any case to prepare the new generation to meet the emerging challeges of the 21st century. This will include the need to be more flexible and farm novel crops; it could also include training for energy production. Such education must not be limited to the universities and agricultural institutes; the National Farmers' Union (NFU), the Agricultural Demonstration and Advisory Service (ADAS) and the many other farming organisations need to be involved.

The public as a whole need to see the role of farming in a different light and be prepared to accept alternative crops and enterprises. This should include the message that energy is as important as food and so prepare the way for energy cropping on the land. Farming has had a bad press in recent years and this may be the time to update its image.

(vi) <u>Research and Demonstration Initiatives.</u>

A glance at the volume of technical research currently being pursued into renewable energy technologies would suggest that there is no shortage of interest and publication in this area. Even so there are some areas which still require much work such as energy storage and others which have yet to be seriously addressed such as integrated food and energy production. In addition a wider research area with considerable implications for the land is the effect of and response to set-aside and the agricultural response to global warming.

Bioengineering research is still in its early days as regards agriculture. Integrated food and energy systems suggest that multi-purpose crops which could be used for animals, humans or energy would be very useful as well as plants and trees which can grow and thrive in unfertilised soils or where there is low rainfall and high temperatures.

As yet there is no demonstration scheme for energy production on the land. Integrated food and energy demonstrations should accompany the research effort for both the conventional and organic regimes.

Appendix 1 — Calculation of the Weight of Livestock from Data given by Thompson of the Energy Input per Head of Beef Cattle, Sows and Porkers at Churn and Stratton Farms

Beef Cattle

Energy per head at Churn for steers is given as 16.5 GJ. From Spedding (1983) the average for extensive and intensive beef production is 45 MJ/kg, so the possible weight of beef cattle at Churn is

$$\frac{16.5 \times 10^{9}}{45.0 \times 10^{6}} \text{ kg} \qquad = 370 \text{ kg}$$

Energy per head at Stratton for 24 month beef cattle is given as 9.1 GJ. Using the Spedding figure the possible weight of beef cattle at Stratton is

$$\frac{9.1 \times 10^{9}}{45.0 \times 10^{6}} \text{ kg} \qquad = 202 \text{ kg}$$

These compare favourably with the *Farmers Weekly* market beef weight for light steers and heifers which lie in the range 330 to 460 kg.

Breeding Sows

Energy per head at Churn for breeding sows is given as 14.0 GJ. Taking from Spedding (1983) the figure of 40 MJ/kg for sows, possible sow weight at Churn is

$$\frac{14.0 \times 10^{9}}{40.0 \times 10^{6}} \text{ kg} \qquad = 350 \text{ kg}$$

Farmers Weekly weight for heavy pigs is over 101 kg. Hence calculated figure on the large side but still of the same order of maginitude.

Porkers

Energy per head at Churn for fattening pigs is given as 2.0 GJ. Taking from Spedding (1983) the figure of 32 MJ/kg for pigs, possible porker weight at Churn is

$$\frac{2.0 \times 10^9}{32.0 \times 10^6} \text{ kg} \qquad = 62 \text{ kg}$$

Farmers Weekly weight for porkers given as 40 to 67 kg - which compares very favourably.

Appendix 2 Biomass Conversion Technologies which could Originate from Feedstock Produced on the Land.

Feedstock		Process	Product
Wood, straw	Dry	Combustion	Steam, electricity
		Pyrolysis	Oils, gases, charcoal
		Gasification	Methane, methanol, ammonia, electricity
		Liquefaction	Methane, ethane, charcoal
Catch crops, farm waste, energy crops, sugars	Wet	Chemical reduction	Oils, hydrocarbons
		Fermentation	Ethanol
		Anaerobic digestion	Methane, fertiliser

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